

T89-10219

JSC 23588

Approaches to the Design of a Housekeeping System in Microgravity

c383

May 1, 1989



National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

TECHNICAL LIBRARY
BUILDING 45
Johnson Space Center
Houston, Texas 77058

LESC - 26823

(NASA-CR-188533) APPROACHES TO THE DESIGN
OF A HOUSEKEEPING SYSTEM IN MICROGRAVITY
(Lockheed Engineering and Sciences Co.)
45 p

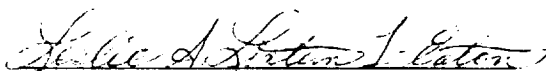
Unclass
Z9/29 0033708

N92-70691

APPROACHES TO THE DESIGN OF A HOUSEKEEPING SYSTEM
IN MICROGRAVITY

PREPARED BY:

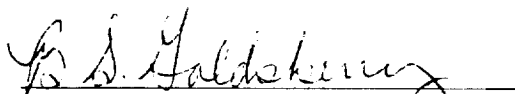
Lockheed ESC



Leslie A. Lintern 1 - Eaton

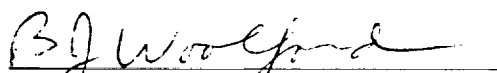
APPROVED BY:

Lockheed ESC

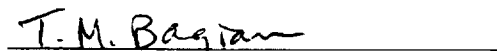


B.S. Goldsberry, Supervisor
Human Factors Section

NASA



B. J. Woolford
Technical Monitor



T. M. Bagian
Head, Crew Interface Analysis
Section

Prepared for
Man - Systems Division
Space and Life Sciences Directorate

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS
MAY, 1989

ACKNOWLEDGEMENTS

The author of this document wishes to thank Betty Goldsberry, Sherry Prud'homme, and Diane Warren. The extensive research they performed on this project was invaluable.

CONTENTS

SECTION	PAGE
1. INTRODUCTION.....	1
1.1 <u>OBJECTIVES OF THE REPORT</u>	1
1.2 <u>OBJECTIVES OF HOUSEKEEPING</u>	1
1.3 <u>ORGANIZATION OF THE REPORT</u>	1
2. MICROORGANISM PREVENTION AND CONTROL.....	1
2.1 <u>AIR FILTERING</u>	1
2.1.1 INTRODUCTION.....	1
2.1.2 PROBLEM STATEMENT.....	1
2.1.3 SKYLAB EXPERIENCES.....	2
2.1.4 SPACE SHUTTLE ACTIVITIES.....	2
2.1.5 SPECIAL CONSIDERATIONS: ANIMALS.....	4
2.1.6 SPACE STATION FREEDOM CONSIDERATIONS.....	5
2.1.7 SPACE STATION FREEDOM GUIDELINES.....	6
2.2 <u>SURFACE CLEANING</u>	7
2.2.1 INTRODUCTION.....	7
2.2.2 PROBLEM STATEMENT.....	7
2.2.3 SKYLAB EXPERIENCES.....	7
2.2.4 SPACE SHUTTLE ACTIVITIES.....	8
2.2.5 SPACE STATION FREEDOM CONSIDERATIONS.....	8
2.2.6 SPACE STATION FREEDOM GUIDELINES.....	8
2.3 <u>TRASH MANAGEMENT</u>	9

2.3.1 INTRODUCTION.....	9
2.3.2 PROBLEM STATEMENT.....	10
2.3.3 SKYLAB EXPERIENCES.....	10
2.3.4 SPACE SHUTTLE ACTIVITIES.....	10
2.3.5 SPACE STATION FREEDOM CONSIDERATIONS.....	11
2.3.6 SPACE STATION FREEDOM GUIDELINES.....	11
3. GENERAL HOUSEKEEPING.....	12
3.1 <u>VACUUMING OPERATIONS</u>	12
3.1.1 INTRODUCTION.....	12
3.1.2 PROBLEM STATEMENT.....	12
3.1.3 SKYLAB EXPERIENCES.....	12
3.1.4 SPACE SHUTTLE ACTIVITIES.....	13
3.1.5 SPACE STATION FREEDOM CONSIDERATIONS.....	18
3.1.6 SPACE STATION FREEDOM GUIDELINES.....	18
3.2 <u>SURFACE CLEANING</u>	19
3.2.1 INTRODUCTION.....	19
3.2.2 PROBLEM STATEMENT.....	19
3.2.3 PERSONAL HYGIENE.....	19
3.2.4 FOOD PREPARATION AND CONSUMPTION.....	29
3.2.5 SLEEP AND RELAXATION.....	31
3.2.6 SUPPORT OPERATIONS.....	32
3.2.7 SPACE STATION FREEDOM GUIDELINES.....	33

4. LOGISTICS.....	34
4.1 <u>INTRODUCTION</u>	34
4.2 <u>PROBLEM STATEMENT</u>	34
4.3 <u>SKYLAB EXPERIENCES</u>	34
4.4 <u>SPACE SHUTTLE ACTIVITIES</u>	35
4.5 <u>SPACE STATION FREEDOM CONSIDERATIONS</u>	35
4.6 <u>SPACE STATION FREEDOM GUIDELINES</u>	36
5. CONCLUDING REMARKS.....	36
6. BIBLIOGRAPHY.....	37

1.0 INTRODUCTION

1.1 OBJECTIVES OF THE REPORT

The objectives of this report are (1) to describe housekeeping procedures and experiences during previous U.S. space missions, (2) to evaluate those previous housekeeping procedures, and (3) to present a set of guidelines which may be used for the design and development of Space Station Freedom housekeeping-related equipment and procedures.

1.2 OBJECTIVES OF HOUSEKEEPING

The habitability of a spacecraft is directed toward satisfying those needs of the crew which depend on the physical environment. Housekeeping is a crucial part of habitability concerned with spacecraft interior hygiene and cleanliness, air filtering, vacuum-cleaning, trash management, and logistics, as it applies to all of the above. Accordingly, housekeeping plays an important role in maintaining the crew's health and safety and, consequently, its morale, comfort, and productivity. Because of the importance of housekeeping for the crew's health and, ultimately, productivity, the Space Station Freedom Habitability Requirements Document states that housekeeping must be carefully incorporated into the Space Station systems and subsystems (NASA, 1983c). The Space Station Freedom Habitability Requirements Document emphasizes, as does this report, the increased importance of housekeeping on a permanently manned spacecraft, or on manned spacecraft with missions of long duration.

1.3 ORGANIZATION OF DOCUMENT

The major topics to be developed in this document are air filtering, surface cleaning, trash management, vacuum-cleaning, and logistics, as it applies to the above. Sections 2 and 3 develop these topics from different aspects.

The focus of Section 2 is on prevention and control of microorganisms for sanitation.

Several methods which aid in the discovery and elimination of harmful bacteria are discussed.

The emphasis in Section 3 is centered on maintenance and general cleaning. The section describes previous problems in maintaining and cleaning in space, and identifies issues requiring further research.

Section 4 describes and evaluates previous logistics systems in spacecraft, as they apply to housekeeping. Additionally, guidelines for the development of a "housekeeping logistics system" for Space Station Freedom are identified, and some potential solutions are described.

2.0 MICROORGANISM PREVENTION AND CONTROL

2.1 AIR FILTERING

2.1.1 INTRODUCTION

The containment of communicable diseases and airborne microorganisms is an important consideration for extended missions and a direct function of the efficacy of housekeeping methods. Without sufficient barriers to prohibit the growth and spread of bacteria, the probability of crew contamination and resulting illness is high. This detriment to crew productivity can be minimized with proper attention to housekeeping methods.

2.1.2 PROBLEM STATEMENT

The level of airborne microbial contaminants has been established as an important factor in the dissemination of infectious diseases. The need to minimize airborne contaminants in hospital operating rooms, burn wards, and immunodeficient patient areas has been extensively documented. The concern is also great in any closed environmental system. The Space Shuttle/Spacelab missions and the eventual Space Station Freedom represent a

unique environment because manned activities in space require closed environmental control systems and occur in micro-gravity. Gravity is an important physical force in reducing the spread of infectious diseases. Microbially laden droplets generated by coughs, sneezes and talking are removed from the air in minutes by the action of gravity; however, these droplets can remain suspended for hours in micro-gravity. Therein lies the possibility of cross contamination among crewmembers, especially for upper respiratory infections which are often spread by the air (Kaplan, 1979). An infective agent can be introduced through any portal of entry in the body, including conjunctiva, mucous membranes and skin, and via particles that are either ingested or inspired (Best & Clayton, 1980).

A well-defined Flight Crew Health Stabilization Program was initiated following a number of prime crew illnesses and crew exposure to persons with infectious illnesses during mission critical periods. As a result of these incidents, it was recognized that crew illness could cause loss in valuable crew training time, postponement of missions, or even compromise crew safety and mission success.

The problems associated with microbial growth became more apparent on Skylab than earlier space programs because Skylab represented the first program in which man lived in space for extended periods. Therefore, earlier space program experiences prior to Skylab are not addressed here.

2.1.3 SKYLAB EXPERIENCES

The NASA space program has placed major emphasis on providing an environment in which the astronaut can perform in comfort and safety with maximum efficiency. The achievement of this objective in manned spacecraft is complicated by the continuous generation of small quantities of contaminants from offgassing of materials and from humans into the closed environment of the spacecraft cabin (Kaplan, 1979).

The presence of several hundred contaminants in the spacecraft atmosphere results from several sources, none of which can be completely eliminated. Principal sources of contaminants from humans are expired air, perspiration, urine, feces, and flatus. Minor sources include thermal decomposition of electrical equipment, plastics, hydraulic fluids, oils, and fire extinguishants, atmospheric gas supply contaminants, leakage from environmental flight control systems, volatile food components, volatile components of personal hygiene articles, and reaction products of contaminant-removal agents (Kaplan, 1979).

Although the Flight Crew Health Stabilization Program was first introduced on Apollo 14, the need for such a program became even more evident in the development of the Skylab missions. The extended periods of crew time in space planned for Skylab increased the probability of in-flight crew illness. The decision was made, therefore, to provide a comprehensive Skylab Flight Crew Health Stabilization Program.

A 21-day isolation period was established for the Skylab crewmen prior to the launch of each mission. The 21-day period was chosen as it covered the incubation period for a majority of infectious disease organisms.

Even with the health stabilization program, some crewmembers on Skylab experienced upper respiratory infections which were caused or aggravated by airborne microbial contaminants (private communication from D. Pierson and J. Ferguson, NASA JSC Medical Sciences Division, 1984). A circulating ventilation loop with filters to clean the air would have removed some of the contaminants.

2.1.4 SPACE SHUTTLE ACTIVITIES

On the Space Shuttle there have been several airflow-related problems. First, there has been a build-up in airborne microor-

ganisms. A crewmember on STS-8 woke up with burning and tearing eyes after sleeping in the airlock. His eyelids were swollen and he had a stuffy nose caused by the irritant. He later noticed a blue haze on his eyeglasses which reappeared about four hours after cleaning them (Myers, 1983c). A crewmember aboard STS-51A complained of frequent periodic sneezing fits and stuffed sinuses. This occurred simultaneously among crewmembers, but did not appear to be related to Space Shuttle events (Myers, 1984e). Crewmembers on the Space Shuttle have complained that the overall cabin air is dirty. The air contained lithium hydroxide (LiOH) dust, dust similar to household dust, blue-gray lint from velcro and clothes, hair, and food particles, in addition to numerous other forms of debris (rocks, nuts, bolts, Roloids, and once, on STS-6, a crewmember noted an Exacto Knife blade floating in the crew module). This debris irritates eyes, noses, and throats, and forms other obvious ingestion hazards (Myers, 1984c).

The debris problem was most notably visible to the STS program during STS-5, when the crew removed two flight deck panels to perform an In-Flight Maintenance (IFM) procedure to swap electrical cables from a failed Display Electronics Unit (DEU) in order to regain a forward CRT (Cathode Ray Tube). The pilot noted that the air-inlet screens on the DEU's were covered with a blue-gray colored lint to a thickness of about 1/4". He cleaned the screens on DEU's 2 and 4 using the on-board vacuum cleaner. On all flights after STS-7, "filter cleaning" became a scheduled, if not routine, maintenance activity, occurring on Days 2 and 5 in the Crew Activity Plan (and on Day 7, if a flight was to be longer than seven days). This activity, which involved the removal of several flight deck panels to clean avionics air inlet screens, cabin fan filters, WCS filters and screens, IMU (Inertial Measurement Units) muffler screens required over two hours of on-orbit activity, due to the numbers of fasteners and panels that had to be removed. Not until STS-26 were the flight deck panels modified to allow easy access due to the installation of hinged doors and

"quick-release" latches. In addition, the avionics "black boxes" in the Avionics Bays 1, 2, and 3 which ingested air for cooling were equipped with new filters, which increased the available surface area to catch debris.

The Microbiology Laboratory, NASA JSC Medical Sciences Division, implemented a Microbial Contamination Control Plan at the onset of the STS missions. One facet of the plan is the qualification and identification of airborne microbial contaminants. The cabin air is evaluated preflight and postflight to assess the efficacy of the environmental control system in removing contaminants. However, the presence of an open hatch, as well as various ground support personnel during sample collection jeopardized the scientific validity of these studies. Currently, the air sampling analysis is done on Earth for chemicals and offgassing, but not necessarily for bacteria (private communication from D. Fricks, NASA JSC Man Systems Division, 1984). Microbial contaminants were monitored during STS-41B with a newly developed particulate strip. This was important during the mission because six rats were housed in a middeck locker as a part of a Shuttle Student Involvement Project Experiment. Scanning electron micrographs of some representative particles were used for identification of the microbial particles trapped by the strip.

Another airflow problem was the insufficient airflow in the urinal and the "slinger" in the Waste Collection System (WCS). Sufficient airflow was required to properly draw liquid and solid waste away from the user's body and into the WCS. The low airflow greatly increased the amount of time spent in using and cleaning the WCS unit. Even when the airflow in the urine hose was increased from 8 to 10 CFM and the operation of this portion of the unit improved, the problem was of such magnitude that JSC In-flight Maintenance (IFM) engineers discovered fecal stains on the panel above the WCS (MO10W) during scheduled Crew Equipment Interface Tests (CEIT's). Subsequently, the WCS was

redesigned to solve all of the earlier on-orbit problems, and the present (1986-88) WCS was totally reconfigured so that few problems were encountered during flight on the missions immediately prior to STS-51L (Jan. 86).

A lack of airflow in the LIOH canister area has also caused some crew discomfort. Crewmembers reported that during the LIOH replacement activity, some type of irritant was present in the air, possibly dust particles from the canisters' flight wrappers. The irritant caused a burning sensation in the crewmembers' throats which induced coughing. After STS-7, the LIOH cans have been "scrubbed" prior to being wrapped, reducing greatly the amount of LIOH dust emitted during flight. Also, the cabin fans were powered off on subsequent flights during the LIOH changeout to reduce the amount of dust contamination.

The Space Shuttle Program offers new problems for health stabilization. A major consideration is that many more people are involved in launch preparations, thus the crew has an increased number of personal contacts prior to a mission. All shuttle missions, including Spacelab and Extended Duration Orbiter flights, have a 7-day isolation period to preclude exposure to persons with infectious illnesses during mission critical periods. Personnel required to be in work areas with the crew are identified and given medical examinations. Those found medically qualified are identified as primary contacts. Primary contacts are instructed to wear surgical masks when within 6 feet of the crewmen. Also, an educational program creating health awareness among employees has been implemented. Posters, signs, and information sheets are widely distributed in this effort (private communication from R. Jennings, NASA JSC Medical Sciences Division, 1989).

Monitoring of air in space flight for airborne microbial and particulate contaminants will continue to be important. The level of particulates has been troublesome, even on

most recent flights prior to the cessation of Shuttle operations. An educational program has been undertaken to teach KSC technicians and supervisors about the importance of cleaning "as the job is done", instead of in a single clean-up operation done before flight. Operations and Maintenance Instructions (OMI 6018) requires cleaning of the orbiter filters and screens prior to and after flight, but does not address the constant vigilance required to combat the debris that has been deposited in the crew module during turn-around maintenance. One of the crew comments regarding the evidence of debris was that they could outfit a hardware store with what they found, including nuts, bolts, and washers.

The portable particulated strip discussed above is an efficient and easy method for monitoring levels and subsequent identification of particles (Pierson, 1984). It does not, however, substitute for stringent cleaning of the vehicle both before and after flight to remove more obviously visible forms of debris which constitute hazards not only to health, but to the safe operation of the orbiter vehicles. Inflight monitoring, the only scientifically sound method for assessing the airborne microbial contaminants during missions, will be required during long missions and may aid in the housekeeping processes. Housekeeping procedures may be successfully accomplished, however, only if all parties who use the vehicles (or Space Station Freedom) are aware that their very presence is a debris problem.

2.1.5 SPECIAL CONSIDERATIONS: ANIMALS

The presence of animals aboard a spacecraft must also be viewed as a unique source of contamination. A more adequate system must be developed for handling the special contamination problems of animals. The Research Animal Holding Facility (RAHF) developed for STS-51B proved to be inadequate for this purpose, as no provision was made for cleaning the facility on-orbit without

disseminating feces around the Spacelab. The crew had to use the orbiter vacuum cleaner to clean this particulate matter from the crew atmosphere. More efficient methods are in order.

The RAHF was designed to prevent cross-contamination between the crew and the animals. Each animal cage contained an integral waste management system, a feeding system, and a watering system, all of which were designed to operate in either zero- or one-g. Additionally, capability to control could be exercised over temperature and day/night cycle lighting. Data display and recording are available on all environmental measurements, as well as life support functions. Panel displays were also provided for air circulation, power system status, warning signals, and operation of the heating and cooling system. Protection against cross-contamination between crew and animal was ostensibly provided through bacteriological isolation. The RAHF waste management system attached to the lower part of each drawer through a slide arrangement beneath the floor of the cages. Access through a door on the drawer's front face permitted changing of the waste tray for missions of more than 10-day duration. The waste generated by animals contained in the RAHF must, however, be more thoroughly considered when allocating trash stowage space. Through the use of slide covers similar to the slide cover of a photographic film pack, the change can be accomplished without cabin contamination. In the zero-gravity environment, air at the velocity of 9.2 m/minute (30 FPM) flows from the top of the cage to the bottom through the waste collection system. Aerodynamic drag on the waste products transports the liquid and solid matter to the collection system. A heat-felted fiberglass pad is impregnated with phosphoric acid for absorption of urine and bacterial growth control. Odor control is accomplished by means of a phosphoric acid-treated activated charcoal bed.

Contamination control for protection of both the animals and the crew consists of air

filtration, a slightly negative-pressure enclosure, and an exhaust-air charcoal bed. Exchange air passes through a 0.5 micrometer High Efficiency Particle Air (HEPA) filter on the inlet side and a 0.3 micrometer HEPA filter on the exhaust side to control particulate contaminants. The test-proven activated charcoal bed under each cage for odor control is supplemented by a charcoal bed in the exhaust air line from the cages. Provisions have been made to dispose of a dead animal in a specially developed canister (private communication from D. Pierson and J. Ferguson, NASA JSC Medical Sciences Division, 1984).

2.1.6 SPACE STATION FREEDOM CONSIDERATIONS

Airflow, in addition to its primary function of ventilation, will be used for toxic gas dissipation, odor control, and particulate matter control (NASA, 1983b). There are two major areas of concern: (1) air contamination monitoring on orbit, and (2) provisions for a work area for the containment of toxins and airborne microorganisms.

A solid sorbent sampler has been developed which samples air on a continuous basis. This unit is manifested on the first flight of a vehicle, on the first flight after a vehicle has been refurbished, and whenever spacelab is flown. Because Space Station Freedom will not be returning to Earth, an inflight real-time analyzer must be developed (private communication from D. Pierson and J. Ferguson, NASA JSC Medical Sciences Division, 1984).

There is a need for a sampling system which can take and analyze bacteria samples from all types of surfaces (air, water, walls, WCS equipment, etc.). One such system that has been developed is the AutoMicrobic System (AMS), manufactured, marketed, and serviced by Vitek System, Inc. This system was designed to detect, enumerate, identify, and establish the antimicrobial agent susceptibility of microorganisms.

The AMS 60 consists of five modules: (1)

filler/sealer module, (2) reader/incubator module, (3) computer control module, (4) data terminal module, and (5) printer module. It can process 60 test microorganisms or samples at one time. In addition to the modules, specially designed and manufactured test cards are an integral part of the system. The AMS performs the microbial test by analysis of microbial growth data. The testcards contain several walls that are filled with biochemical mixtures that allow unique metabolic reactions to occur in the presence of microorganisms. The data are determined by the electro-optical detection of microbial growth within the walls of the test cards. The cards are inoculated with the specimen, processed automatically, and at the completion of the test cycle, the results are printed out. In addition to controlling the test process and determining final test results, the computer module provides self-calibration instructions to the reader module, and continuously monitors and controls several key system parameters (Vitek, 1980).

Although the Vitek system has not currently been selected for flight, this type of system could greatly enhance all aspects of sanitary housekeeping. For example, the AMS could identify a specific bacteria growing on a surface, and the correct cleaning agent to kill this bacteria could then be applied.

No firm commitment exists as to the time crewmen should spend in a Health Stabilization Program in preparation for Space Station Freedom duty. Suggestions have been in the range of 10 to 14 days. This period of time is considered sufficient for incipient illnesses to appear.

A prevention method for air contamination is to provide a work area for toxic and microbic containment. For example, a General Purpose Work Station (GPWS) has been developed at the NASA Ames Research Center for use on the fourth Spacelab flight. The station would be usable by one or two operators in zero-g. The GPWS will furnish Life Sciences Flight Experiments with four

capabilities: (1) biological protection, (2) control of liquids and of chemical vapors, (3) housekeeping, storage, and restraint of equipment and specimens, and (4) work surface, lights, and utilities.

The GPWS glove box has laminar-flow capability and isolates the operator from the test material. Its work area meets the standards of a Class II laminar biohazard cabinet defined by the National Sanitation Foundation and provides both personnel and product protection from low to moderate risk biological agents. In conjunction with the trace contamination control system, it prevents build-up of harmful chemicals in the closed Spacelab cabin. Fully raising the front panel provides a 24-inch-high opening for access to complete biological isolation. The front panel will be closed with access through silicone rubber slits. Net-covered port accessories prevent the escape of animals and liquids. A viewport and glove ports on the side allow assistance by a second operator.

During system operation, laminar airflow passes downward through the rectangular work area at a velocity of 60 fpm, trapping liquids, vapors, and particulates. Baffles force entrained liquids onto replaceable absorbent pads. About 20 cfm of air are bled out of the bench through a canister where a bed of lithium hydroxide, charcoal, and Purafil removes chemical contaminants. This air is replaced through the front slits.

Tests were run in the near 0-g environment of parabolic flights in a KC-135 aircraft. Smoke, aqueous aerosols, liquid droplets, chemical spills, and particulates were introduced into the cabinet and observed by high-speed photography. Containment was demonstrated in all cases, and positive entrainment was shown even for very small particles, such as smoke and aerosols (Lockheed, 1984).

2.1.7 SPACE STATION FREEDOM GUIDELINES

1. An air sampling system capable of taking accurate samples, including, but not limited to bacteria samples, from all materials, gases, and surfaces, permanently installed and automatically monitored, should be provided in order to instigate appropriate and timely measures for the detection and control of air contaminants.

2. Space Station Freedom should have separate, circulating, and filtered ventilation air loops for cabin and avionics air systems. These should have sensors to show when filters need to be cleaned, not just when they become so clogged that they degrade system operation. The filters on both systems must be easily accessible, and adequate means provided to clean them (something more adequate than the existing Shuttle vacuum cleaner).

3. A general purpose work station with proper biological protection and isolation features should be provided for all work involving potentially harmful or contaminated materials.

4. When animals are flown, an adequate animal holding facility which, at a minimum, prevents cross-contamination between the crew and the animals through bacteriological isolation is imperative.

5. Airflow must be assured in the waste collection system, if air is intended to be used as a functional part of the system.

6. If a LIOH scrubber system is used in the cabin, it must be assured of proper airflow, and the replaceable canisters must not cause debris in the cabin atmosphere.

7. Positive airflow must be assured throughout the cabin and avionics areas, through two separate systems, in order to allow the debris in each system (cabin, avionics, WCS, etc.) to be trapped on and removed from filters.

8. The air-filtering system should be designed to prevent an excess of air-entrained debris from clogging screens and filters. The use of devices such as particle separators, such as those used on turbine engines to prevent debris ingestion, should be investigated.

9. In addition to provision of a maintenance workstation, adequate maintenance tools should be provided, such that they do not produce a debris hazard while in use. (eg., drills, soldering irons, welders, saws, glues, lubricants, etc.).

2.2 SURFACE CLEANING

2.2.1 INTRODUCTION

Housekeeping on a Space Station Freedom system has preventative medical implications. Major types of infections occurring in space travel include dermal, upper respiratory tract, pulmonary, urinary, and food borne infections. Most inflight illnesses have been upper respiratory infections. The application of sanitation methods incorporated into routine housekeeping could prevent many of these infections (NASA, 1983b).

2.2.2. PROBLEM STATEMENT

Sanitation is more important within the confines of a spacecraft than on Earth. Studies have shown that the population of some microbes and fungi can increase rapidly in a confined microgravity environment. As a result, the dining, grooming, and sleeping areas on a spacecraft should be separated as much as possible, and cleaned (NASA, 1984a) as a measure to significantly enhance preventative medicine efforts.

2.2.3 SKYLAB EXPERIENCES

The short duration of pre-Skylab missions reduced or eliminated the need for surface cleaning procedures. Therefore, a historical review of cleaning issues will begin with the Skylab program.

The lack of sanitary housekeeping on Skylab 3 caused much contamination. This generated concern about the habitability of the spacecraft for the crew of Skylab 4. There were skin infections due to a staphylococcus build-up, and cross-contamination among crewmembers. The staphylococcus build-up may have occurred due to a lack of disinfectant procedures carried out in the Waste Management Compartment, Trash Airlock, Galley, and exercise area (private communication from D. Pierson and J. Ferguson, NASA JSC Medical Sciences Division, 1984).

2.2.4 SPACE SHUTTLE ACTIVITIES

Since the Space Shuttle missions are of relatively short duration, a sanitary wipedown of surfaces during on-orbit operations is not regularly scheduled, although biocide wipes are provided for spills and emergency cleanups. With mission lengths of only five to seven days, the importance of preventing bacterial growth, mold, mildew, and fungi should not be minimized. An infection can be transmitted in much less time than a week. While maintenance procedures require a thorough cleaning during ground turn-around in the Orbiter Processing Facility, such was not the case during the frenetic activity of flight operations during 1983-1985. JSC In-Flight Maintenance engineers, flight crews, and program office officials have found fecal matter adhering to the panels adjacent to the WCS. Air duct interiors were found to contain large amounts of debris which was left from flight-to-flight and could obviously contribute to a microbial infection situation. To date, procedures have not been instituted at KSC to inspect and clean the interior surfaces of the Orbiter air ducts; and not until great emphasis was placed on the fecal problem were the appropriate panels surface-cleaned. Because the appropriate cleaning was not regularly done on the ground, the on-orbit cleanliness suffered. Greater attention should have been paid to ground cleaning and debris removal; the same will be true for Space Station Freedom assembly operations.

2.2.5 SPACE STATION FREEDOM CONSIDERATIONS

The proposed manned Space Station Freedom will not return to Earth for maintenance and cleaning. Therefore, routine housekeeping must be incorporated into Space Station Freedom activity planning, and the hardware designed so that housekeeping can be performed easily by the crews.

The long duration of orbit operations for the Space Station Freedom missions will require a scheduled wipedown of surfaces. A biocidal detergent is recommended to remove dust and dirt from all surfaces, especially in the dining, personal hygiene, sleeping, and food preparation areas. Specific personal hygiene equipment to be cleaned includes the WCS, showers, and hand/face washers. Research has shown that the exclusive use of soap with no biocidal agent results in a high likelihood of bacterial growth (Werner, 1975). Although soap reduces the Gram-positive cocci (eg. staphylococcus), it is almost ineffective against problem germs such as Klebiellae. Phenol-base products have yielded the best results on this type of bacteria, even though they may irritate skin and leave an unpleasant residue (Moore, 1968). Other very effective disinfectants contain a specially prepared iodine solution, such as the ingredient found in the biocide wipes presently used on spacecraft. In addition, a pleasant scent may be added to detergents which would enhance the living and working areas.

Molds and mildew flourish on surfaces which are damp, wet, poorly ventilated, and poorly lit (Libien, 1976). Therefore, grooming, dining, and food preparation areas should be aired, dried, and illuminated regularly. Cleaning would be facilitated by an effective air filtration system and smooth surfaces on walls, floors, counters, and within the interiors of air ducts. Air ducting should be accessible for interior cleaning. Cracks and crevices should also be avoided in the design of equipment to be housed within the Station, so that thorough cleaning can be accomplished, and

to prevent the infiltration of debris behind panels.

A sampling system which can take bacterial samples from all types of surfaces and materials (air, water, walls, etc.) is needed in the closed environmental system of the spacecraft. The requirements for this system include: (1) the ability to identify a specific bacteria growing on a surface, and (2) the ability to identify the correct cleaning agent to kill the bacteria. The Automicrobic System described under section 2.1.5 is one method which can meet these requirements.

One method to prevent microbial growth on wall surfaces would be the use of a vinyl wallpaper which contains germicidal additives. This type of wallpaper eliminates *Staphylococcus aureus* (staph) within 24 hours of contact (Tucker and Schneider, 1976). Some type of "peel-away" system in which "used" wallpaper that is no longer staph resistant could be removed, leaving fresh wallpaper, might be feasible, as long as other safety and debris considerations are adhered to: the system does not cause additional debris within the crew module, and it does not offgas or burn readily. Germicidal wallpaper would be a step toward reducing crew time expended on housekeeping, since a sanitary wipedown of all surfaces would be unnecessary.

2.2.6 SPACE STATION FREEDOM GUIDELINES

1. A system which can take bacteria samples from all types of surfaces and materials, and which can identify a cleaning agent to kill the bacteria should be instituted as an integral system of housekeeping management. The system should be, as nearly as possible, integral to the interior design of the Space Station Freedom, and should include its own caution and warning systems to alert the crew of a microbial attack.

2. Measures to prevent microbial growth, such as vinyl wallpaper which contains germicidal additives, should be examined and

tested for applicability to Space Station Freedom. Effectiveness, cost, maintainability, and offgassing properties should be thoroughly analyzed and tested.

3. The Space Station Freedom interior panels and interface equipment (in addition to Personal Hygiene Equipment) must be designed so that all cracks and crevices are removed or minimized to inhibit the growth of bacteria.

4. All station equipment, including avionics, environmental, electrical, and normally inhabited areas (grooming, dining, sleeping, food preparation areas) must be aired, dried, and illuminated regularly to prevent the growth of mold and mildew.

5. The detergent used to clean surfaces in the spacecraft should have either a phenol or iodine base in order to be effective against germs. The detergent should also be low-sudsing, safe for use in a closed environment, and compatible with onboard water reclamation and/or waste disposal system.

2.3 TRASH MANAGEMENT

2.3.1 INTRODUCTION

Trash management involves collecting wet and dry trash, changing trash receptacle liners, stowing trash bags, venting wet trash in case of offgassing, and treating biologically active trash. The major sources of trash are food, clothing, towels, and teleprinter paper (NASA, 1983b). Wet trash is defined as anything which could offgas. This includes food, washcloths, clothes, expended wipes, and anything that could decay (private communication from D. Fricks, NASA/JSC Man-Systems Division, 1984). The dry trash is mostly towels and clothing (private communication from L.W. Lew, NASA Training Division, 1984).

2.3.2 PROBLEM STATEMENT

The amount of trash generated on space flights and methods for dealing with it have been a growing concern. Current stowage provisions on the Space Shuttle have proven to be inadequate, even for the relatively short missions it flies. Sanitary housekeeping procedures for dealing with trash are important to reduce bacterial growth and to insure a clean, habitable, environment.

2.3.3 SKYLAB EXPERIENCES

The short duration of missions of pre-Skylab programs reduced the need for trash management procedures. Therefore, a historical review of trash management will begin with Skylab experiences.

On Skylab, all biologically active trash items, including dirty laundry, systems filters, used tissues, and food cans were put in bags and dumped via a Trash Airlock into the waste tank. Inactive items were placed in bags in the plenum area (private communication from R. Marak, NASA JSC Crew Systems Division, 1984). However, the trash was not treated, and the Trash Airlock was the dirtiest area aboard Skylab. It is speculated that most of the bacteria onboard grew there (Dalton, 1975).

On Skylab, trash bags were hanging on the wall in the wardroom, and in other areas of the spacecraft, and stuck out from the wall at a 45 degree angle and got in the way of traffic. This seemed to be their "neutral position". The bags needed to be restrained at both ends (Dalton, 1974b).

2.3.4 SPACE SHUTTLE ACTIVITIES

A wide disparity exists among Space Shuttle crews about the definition of wet and dry trash. For instance, on STS-8 the food went into the dry trash (Myers, 1983c). On STS-41G, food, cans, and cookies were designated as dry trash (Myers, 1984d). Damp washcloths were put in the laundry bag instead of the wet trash on STS 51-A (Myers, 1984e). Clearly, defining wet and dry trash consistently

precedes an effective trash management system.

To assist with the proper disposal of damp washcloths and handtowels, a "dirty towel can" and auxiliary wet trash storage were added to the WMS area. Only two wipes may be disposed into the commode unit at a time. Any additional wipes or washcloths used may be placed in the dirty towel can. After each use, the paper bag liner is removed and disposed in the nearby auxiliary wet trash storage and a fresh paper bag liner is velcroed in the towel can.

On the Space Shuttle, there is a problem with positive retention of wet trash, especially when access to the container is made (NASA, 1983b). The container is a solid volume, lined with a polyethylene bag, which is vented at the top of the volume by a 1/4" stainless steel line connected to an overboard vacuum. Because the vent is located at the top of the container, the end at which the crewmember deposits wet trash, the trash already in the volume migrates toward the vent, and the crew must push new trash through the existing trash in order to get it into the container. Almost every crew has found this a very unsanitary arrangement (private communication from G.E. Johnson, JSC MOD/IFM-Crew Systems Section, 1988).

Spacelab crewmembers thought that split septum bags with inner liners would work much better than the bags presently used for retention purposes (Myers, 1983b). A crewmember on STS-41C suggested that the bags be redesigned so that more of the volume in the bags would be usable. The trash floated in the container, so that the bag always looked full when opened (communication from D. Fricks, NASA JSC Man-Systems Division, 1984). A new type of trash bag was flown on STS-41-G which was supposed to allow better acceptance of the system, but the crewmember, who had flown before, found it didn't make much difference (Myers, 1984d). The STS-51A crew stowed trash directly in the trash containers because they did not realize

that there were liners for the containers; they recommended putting the liners in the bags before launch (Myers, 1984e).

On the Space Shuttle, there has been a sanitation problem with garbage floating around in trash receptacles before being emptied (communication from D. Fricks, NASA JSC Man-Systems Division, 1984). Since the trash bags always look full, the crewmember must shove his hand down into the trash bag to place items in the bag. This is not a sanitary or enjoyable process, according to the crew, yet it must be performed every time wet trash is generated (Myers, 1983c). One crew suggested a glove for use in pushing trash around within the bags (Myers, 1984c). Some crewmembers have complained of odor from decayed food in the wet trash.

The wet trash container interfaces with the Waste Management System though the vacuum vent quick disconnect in order to vent gases which may develop (NASA, 1983a). The quick disconnect does not isolate microorganisms, and crew contamination may be the result (Myers, 1982a). A filter or other sanitary treatment mechanism might remedy this situation. As mentioned above, moving the vacuum vent inlet from the top of the bag to the bottom would help in causing the trash to migrate to the bottom of the bag. The capacity of the wet trash container is 8 cubic feet.

Empty food containers are stored in the wet trash storage. The containers are clustered together in threes and inserted through hinged, spring-loaded circular ports. The door size limits condensing the trash any further. If the diameter of the port was 1/2 inch larger, many more food containers could have been packed together (Myers, 1983b).

A trash compactor would reduce the volume of waste. It is assumed that food residue is 10 percent of the total food volume. Packaging and food waste resulting from a crew of eight who are on orbit for one month would require 11 cubic feet of trash stowage

space. This volume would be much less if a trash compactor were used (Rappole, Louvier, and Sivaraman, 1983). Food systems should provide containers that are compactible for stowage (communication from D. Fricks, NASA JSC Man-Systems Division, 1984).

2.3.5 SPACE STATION FREEDOM CONSIDERATIONS

Several issues must be further examined and developed to attain the goal of an efficient, sanitary trash management system. These issues include the development of a trash compactor, design of new and more efficient trash containers, and standardization of procedures used to manage trash. It is proposed that trash on the Space Station Freedom be temporarily stored and returned to Earth (NASA, 1983b). Another alternative might be the development of systems to "incinerate", decompose, or otherwise break down the trash into very small volumes (dust-sized), and eliminate trash overboard.

2.3.6 SPACE STATION FREEDOM GUIDELINES

1. The quick disconnects and other attachment mechanisms which may interface with a waste management system should include the ability to isolate microorganisms with filters or other means, such as a very high tolerance specification for how much material may escape when the disconnect is accomplished. Most water quick disconnects have a tolerance of 1 drop of fluid allowed during connect/disconnect.

2. The temporary trash collection points should be readily accessible and located near areas of the greatest trash generation. The trash collection bags should not interfere with movement in passageways or with workstation, sleeping, or other tasks.

3. The trash containers should be designed for positive retention of trash, especially during the periods when they are accessed by the crew.

4. The periodic removal and stowage of full bags must be planned. Full trash bags must be stowed in an isolated area designed for this purpose, until they can be shuttled back to Earth, or disposed of in other, more efficient and cost-effective means.

5. Biologically active trash should be treated to render it safe from growth of microorganisms or production of gasses which would impair crew health.

6. A trash compactor should be designed and stowed as part of the standard equipment. It should be used with all possible trash to reduce the volume necessary for trash stowage and transfer.

7. The volume of trash generated during a specific time should be accurately calculated, and the necessary tools and stowage space should be provided in order to adequately manage such trash.

3.0 GENERAL HOUSEKEEPING

3.1 VACUUM CLEANER OPERATION

3.1.1 INTRODUCTION

Vacuum cleaning is a method that uses suction to remove unwanted material. It can be accomplished by the use of a standard electrical appliance (AC or DC) or by using hoses and attachments connected to the vacuum of space. Both methods have been used on spacecraft. Vacuum cleaning can (1) remove dust, lint, liquids, and other debris from various surfaces; (2) collect the debris into a centralized area; (3) provide easy removal and/or stowage of the debris; and (4) reduce the physical contact with the debris by crewmembers, thereby helping to maintain a clean living and working environment.

3.1.2 PROBLEM STATEMENT

A vacuum cleaning should remove various types of wet and dry particulate matter from

a surface or the cabin atmosphere and allow for easy disposal of the debris. Crewmembers have criticized the noise level of the Orbiter vacuum cleaner. A newer, quieter, more efficient vacuum cleaner should be designed and manifested.

3.1.3 SKYLAB EXPERIENCES

Previous space programs have used vacuum cleaning systems. Skylab, however, was the first spacecraft in which crewmembers lived and worked in space for several months and performed major housekeeping tasks. Therefore, the historical review of cleaning a spacecraft using a vacuum cleaner will begin with Skylab experiences.

On Skylab, the vacuum cleaner was used for cleaning filters and removing water from the shower stalls. Some of the filters on Skylab were a part of the air revitalization system (ARS). These filters collected various types of debris, including tape, lint, hair, washers, tissues, nail clippings, and food crumbs. Other filters were used to protect equipment from foreign debris. Both the cabin and avionics air filters required access in order for them to be cleaned with the vacuum cleaner. However, many of these filters were difficult to access due to the design of the equipment. In addition, crewmembers reported that the vacuum cleaner had difficulty picking up small debris (eg. lint, hair, and food crumbs), due to the limited suction capability of the unit (Johnson, 1974).

On Skylab, crewmembers cleaned the shower after each use, spending up to 30 minutes using the vacuum cleaner. Crewmembers reported that the vacuum cleaner was inefficient for removing water during the shower-cleaning operation because: (1) the process was time-consuming due to poor suction, (2) the water collected in the vacuum cleaner housing, (3) the vacuum cleaner filter absorbed water, and (4) the vacuum cleaner bag required replacement after each use (Johnson, 1974).

Crewmembers recommended several

design changes that could improve the capability and versatility of the vacuum cleaner: (1) provide more suction power, (2) provide an outlet for blowing air in order to keep equipment cool or to dislodge debris from filters, (3) provide lights on the vacuum cleaner housing and attachments to illuminate the area being cleaned, and (4) provide attachments that conform to the surface being cleaned (Johnson, 1974).

3.1.4 SPACE SHUTTLE ACTIVITIES

The Space Shuttle vacuum cleaner is primarily used to clean onboard filters. While it is probably not the best tool now available for this task, it has proven sufficient. It is a standard Hoover model canister vacuum cleaner modified to be energized by 115 volt 400 Hz AC orbiter current. Its noise level therefore is considerable. It produces suction of 22 cubic feet per minute (CFM) through a 1" diameter nozzle (Fig. 1), which has proven to be more than adequate for Orbiter cleaning tasks. Several different attachments have been designed for the specific uses on board the Space Shuttle (Fig. 2). The filters and screens that are regularly (normally on Day 2 and Day 5 of a standard 7-day mission) cleaned aboard the Shuttle are associated with avionics LRU's (line replaceable units) and cabin fan filters (Fig. 3). Examples of avionics filters/screens that are cleaned include flight deck "black boxes": Display Electronics Units (Fig. 4), Display Driver Units, Audio Switching Units, Video Switching Units, Manipulator Controller Interface Unit (Fig. 5), and Inertial Measurement Units (Fig. 6). In addition, flight-specific LRU's which interface with the cabin air system are also cleaned, as well as the WCS air inlet screens (Fig. 7). The filters, by virtue of using cabin air for their cooling, collect numerous types of debris and objects from the cabin air system, such as nuts, bolts, lint, hair, and numerous other types of material.

The IMU screens have been modified from the earlier OFT (operational flight test) con-

figuration, and are located on the external surface of the IMU muffler assembly. They are cleaned using a standard "crevice tool" attached to the vacuum cleaner hose. The IMU fans are pretty efficient in circulating cabin air, and therefore have been very helpful in cleaning debris from the atmosphere. They have been reported by crewmembers to be "very dirty" on each cleaning occurrence.

The vacuum cleaner has been used on two Spacelab missions, in addition to its scheduled use on the Orbiter. On STS-51B (SL-3) it was used to clean up animal feces escaping from the RAHF (Research Animal Holding Facility); on STS-61A (SL-D1) it was used to clean debris from the MHF (Mirror Heating Facility). Prior to SL-D1, there was no AC utility outlet in Spacelab with which the vacuum could interface; on SL-3, an unused AC experiment outlet was used to power the vacuum cleaner; a special AC "pigtail" (extension cord) was carried which allowed the vacuum cleaner to be plugged into this outlet.

Crewmembers recommended some design changes to improve the vacuum cleaner unit and its capability: (1) reduce the noise level of the unit; (2) evaluate the use of a smaller, handheld vacuum cleaner that uses DC versus AC power (there are many more DC outlets on the orbiter and Spacelab than AC outlets); (3) design equipment so that filters are easily accessible.

Of those three recommendations, at this writing, only one has been implemented. On STS-26, flight deck filters were easily accessed by a modification to flight deck panels which placed doors in the panels which are easily opened to allow access to the LRU filters. This modification cut the time previously spent on in-flight filter cleaning at least in half. It previously required about 2 1/2 hours to clean filters, due to the fact that several panels had to be entirely removed to access filters. Each panel contained as many as 27 fasteners, each of which had to be loosened or removed to free the panel from its mounting position. In addition to new panels, the Avionics Bay avionics

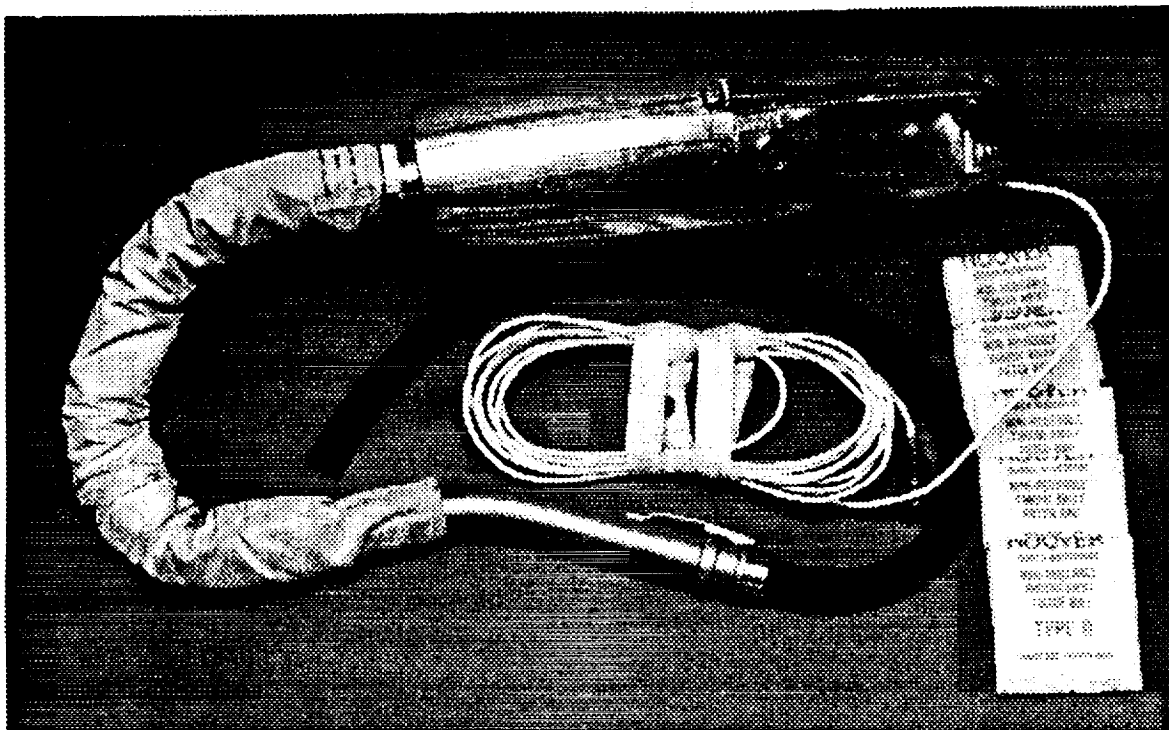


Figure 1. Vacuum Cleaner with Flexible Hose Attachment

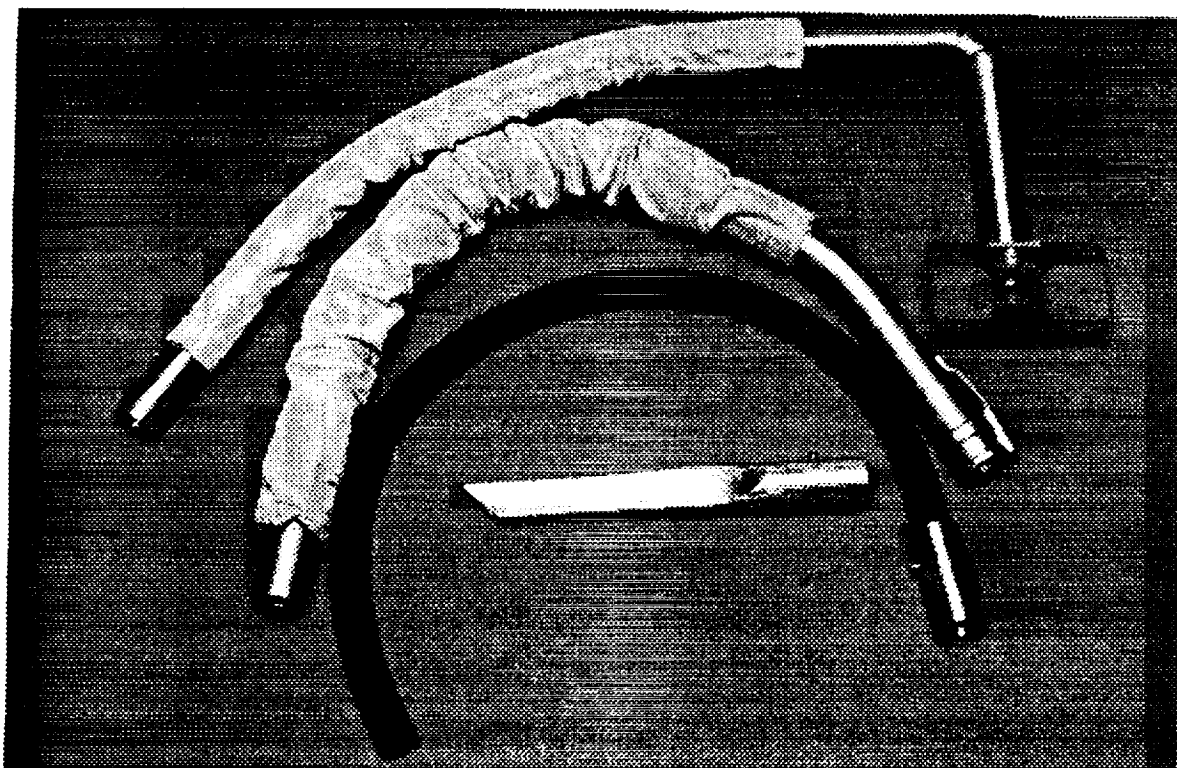


Figure 2. Vacuum Cleaner Attachments

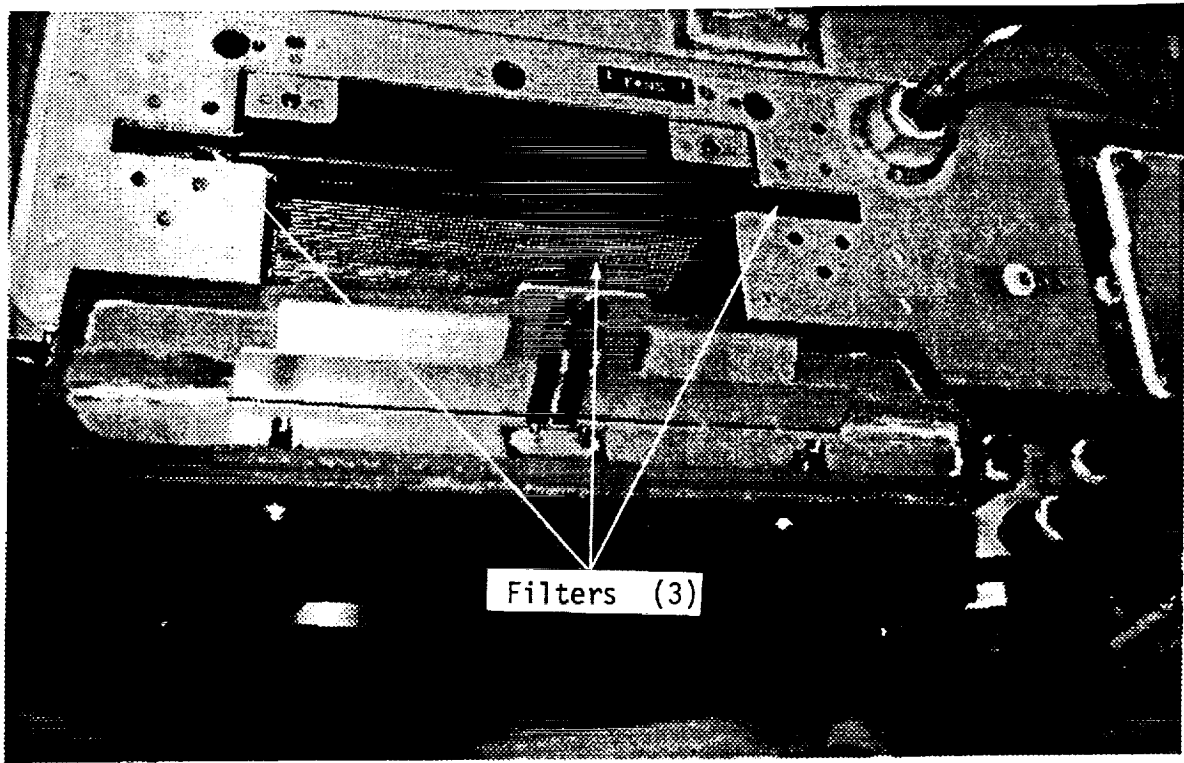


Figure 3. Cabin Fan Filter

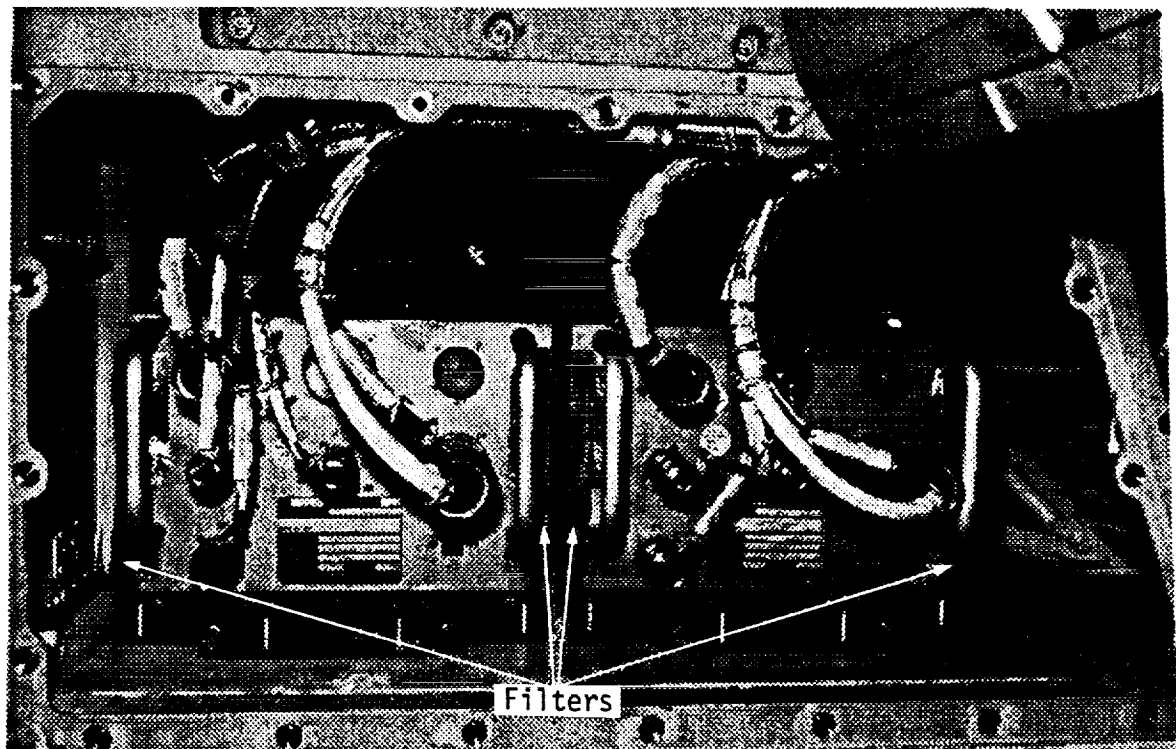


Figure 4. Display Electronics Units 2 & 4 Filters

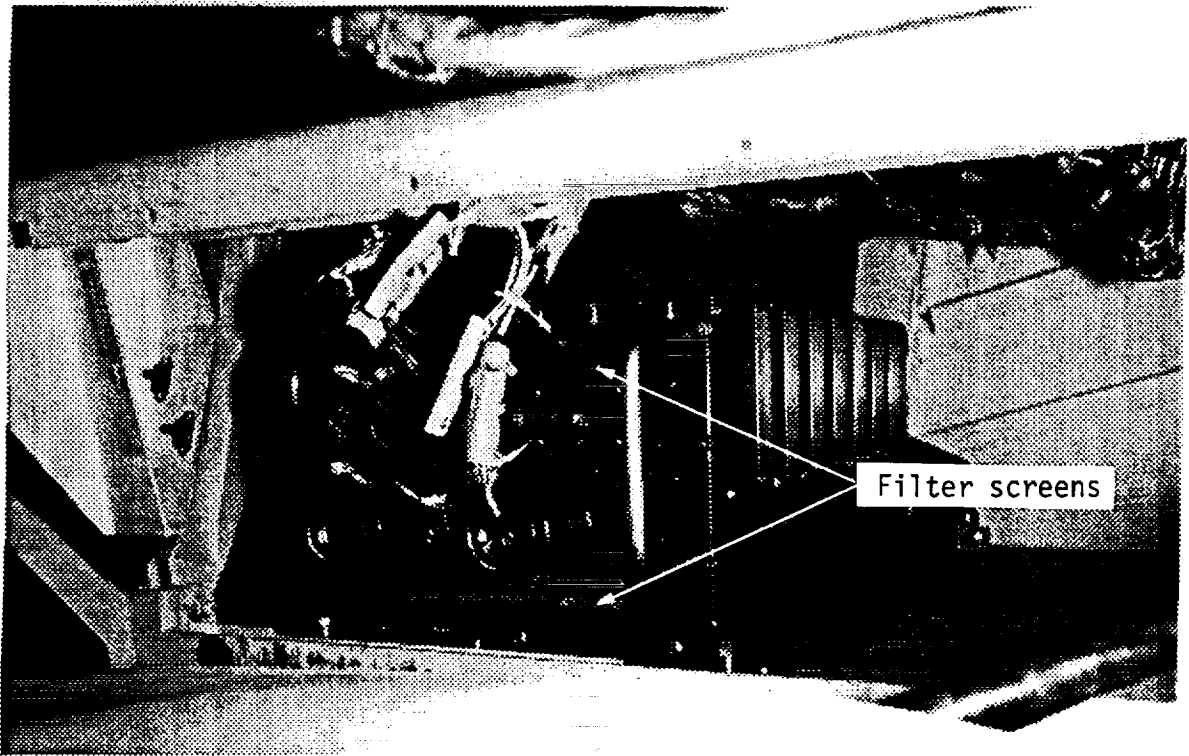


Figure 5. Manipulator Control Interface Unit Filters

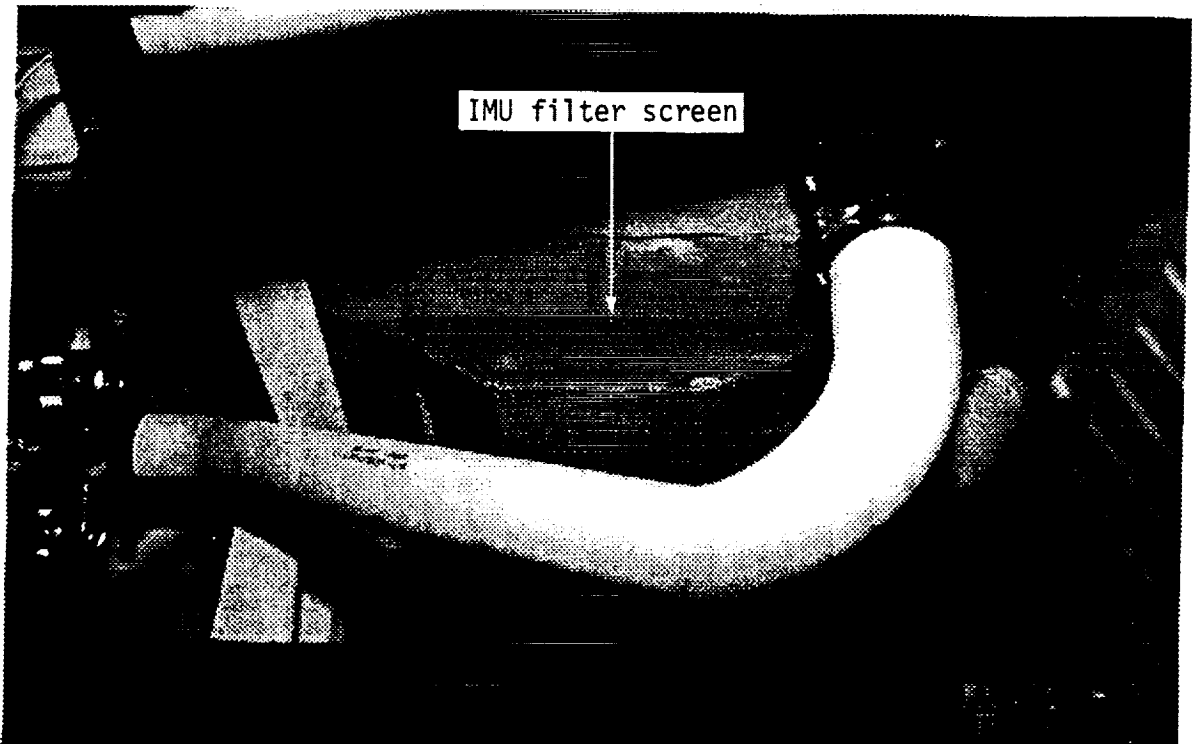


Figure 6. Inertial Measurement Unit Filters

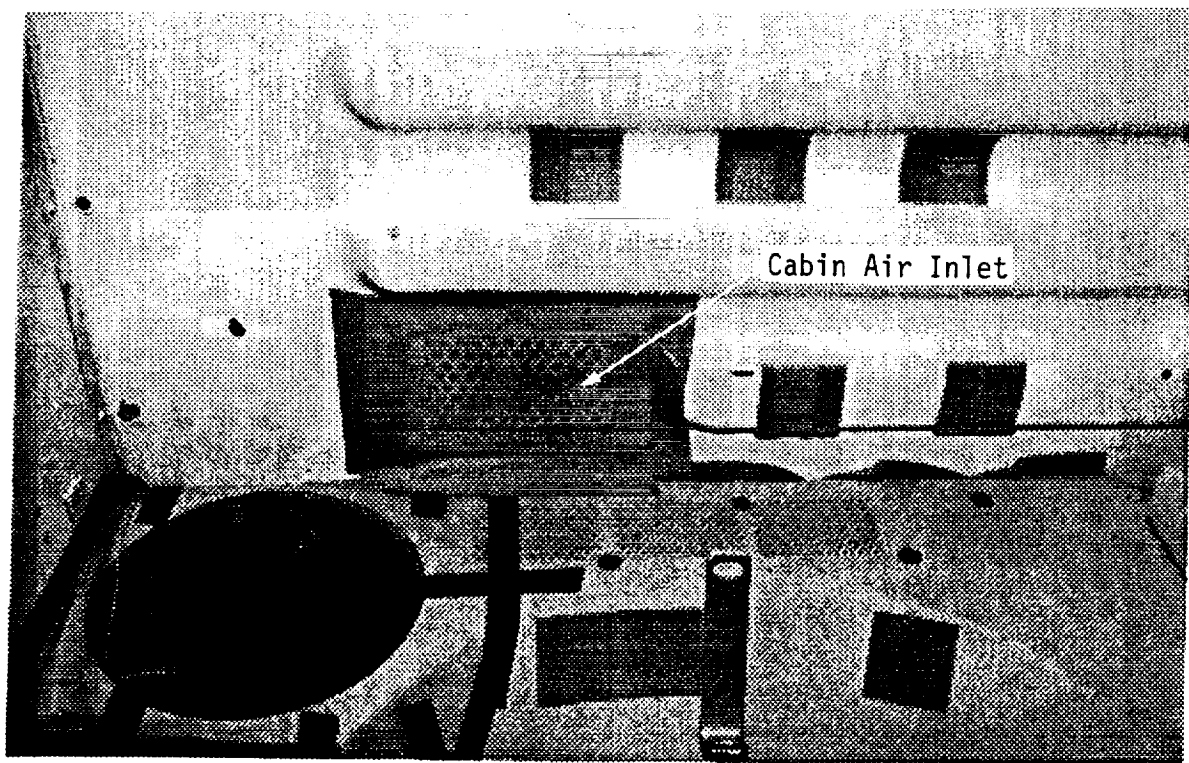


Figure 7. Middeck WCS Air Inlet Screens

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

boxes have been equipped with new filters which increase the surface area of the previous screens, and are removable both in flight and on the ground. A considerable savings in ground turn-around time should be seen because of this modification, and its impact on EDO (Extended Duration Orbiter) flights may be extensive.

3.1.5 SPACE STATION FREEDOM CONSIDERATIONS

As described in the sections on Skylab and Space Shuttle, the vacuum cleaner was used to remove various types of wet and dry matter, as well as to collect and dispose of the debris with a limited amount of physical contact. To maintain a clean living and working environment on Space Station Freedom, a vacuum cleaning system will need to be designed that will perform the same types of functions, in addition to the abilities to remove real or potentially toxic or dangerous substances.

The vacuum cleaning system for Space Station Freedom should be designed considering the following NASA constraints: (1) minimal time for preflight training of crewmembers; (2) minimal effort and time for maintenance, repair, and replacement of equipment; (3) maximum use of automation where appropriate; and (4) use of limited available resources, such as electrical power, water, and stowage volume (NASA, 1984c). NASA also states that a vacuum cleaning system should: (1) collect and retain both wet and dry particulate matter, as well as liquids, via gravity substitute airflow; (2) be non-propulsive; (3) have sufficient suction to collect debris; (4) consist of one vacuum cleaner unit; (5) have an assortment of attachments; and (6) have an abundant supply of bags (NASA, 1983b).

Further research is necessary to determine and evaluate alternative methods for the development of a Space Station Freedom vacuum cleaning system. The applicability of one or several central vacuuming system(s), however, should be evaluated as a possible

alternative. A system similar to existing Earth systems which conceal the central unit inside of walls and have several outlets in remote locations could be considered.

On Space Station Freedom, a centralized vacuuming system could automate the transfer of wet and dry debris by moving it directly into a disposal tank for chemical treatment and/or compaction. The systems could also reduce the amount of crewmember contact with debris, and reduce the time required to transfer debris from one temporary location to a central collection area. Some concerns surrounding such a system center around the ability to find lost articles inside the system, and providing for maintenance of the equipment.

3.1.6 SPACE STATION FREEDOM GUIDELINES

Based upon the Skylab and Space Shuttle experiences, as well as the Space Station Freedom requirements, several guidelines for the development of a vacuuming cleaning system can be identified:

1. Space Station Freedom equipment requiring maintenance and cleaning should be easily accessible.
2. The system should provide ample suction capability for the collection and retention of wet and dry particulate matter, as well as liquids, via gravity substitute airflow.
3. The system should have a safe noise level during operation.
4. An assortment of attachments, which conform to the surface being cleaned should be provided along with an ample supply of bags, or other suitable receptacle.
5. Lights should be attached to the vacuum cleaner housing and to the ends of the attachments.
6. The system should include a blower

outlet with sufficient power to dislodge debris.

7. The system should be non-propulsive.

8. The system should require a minimal amount of crew training and be easy to use.

9. The equipment used should be easy to maintain, repair, and replace.

10. The system should be flexible and expandable to adapt to the needs of Space Station Freedom systems.

11. Automation should be used wherever possible.

3.2 SURFACE CLEANING

3.2.1 INTRODUCTION

Cleaning is defined as freeing an area of dirt and other impurities (The American Heritage Dictionary, 1982). The purpose of cleaning is to foster the physical and mental well-being of the individuals that must inhabit the area. Surface cleaning on Space Station Freedom is defined as a subsystem of a general cleaning system, and will include the routines and supplies necessary to eliminate dirt and impurities found on the exterior of equipment and clothing, walls, floors, and ceilings.

This section establishes guidelines for the cleaning of surfaces on Space Station Freedom. Identifying types of dirt or debris, the cleaning equipment necessary to ensure its elimination are the primary goals in establishing guidelines for a Space Station Freedom cleaning system. The various functions of the system can then be outlined, and the supplies, routines, and management systems required to support those functions can be described. In this section, previous space missions are used to identify and clarify what is meant by "dirt", and the NASA Space Station Freedom Phase B RFP (Request for Proposal) identify equipment deemed necessary by the Agency to meet these ends. Additional requirements are suggested. The supplies and routines sug-

gested are derived from previous experiences in space, and from relevant literature published throughout the industry.

3.2.2 PROBLEM STATEMENT

Research and experience have shown that the presence of waste products on exterior surfaces of equipment are a contamination source and can be health hazards. Bacteria grow on these surfaces and can be transferred to individuals on contact. Regular surface cleaning, therefore, will remove the contaminants and create a healthier environment.

Since Space Shuttle missions are of relatively short duration, only critical surface cleaning is performed on-orbit. Because crew time is at a premium, surface cleaning is not a scheduled on-orbit task. Space Station, on the other hand, will require scheduled surface cleaning, and the time to perform this activity must be incorporated into crew activity plans. In the proposed Space Station Freedom, surface cleaning will involve the maintenance of at least two habitation modules. Four types of crew activity which relate to surface cleaning are envisioned to be performed in these modules:

- (1) Personal hygiene
- (2) Food preparation and consumption
- (3) Sleep and relaxation
- (4) Support operations.

Unlike earlier spacecraft, the Space Station Freedom will provide discrete facilities designed to accomplish these activities. This section focuses on the types of equipment to be cleaned in each of these modules. Existing equipment will be viewed from a historical perspective, and surface cleaning guidelines for Space Station Freedom will be considered.

3.2.3 PERSONAL HYGIENE

Personal hygiene activities provide equipment for body waste collection and personal

cleanliness. Types of equipment to be cleaned are waste collection units, showers, hand/face washers, and grooming compartments. The sections address issues of hygiene only as they relate to surface cleaning of equipment.

3.2.3.1 WASTE COLLECTION UNITS

Waste collection units collect, treat, and store human body waste in a sanitary, odorless manner.

3.2.3.1.1 HISTORICAL BACKGROUND

The Mercury and Gemini modules had just enough volume for the crew to sit in their seats or couches and reach their instruments; therefore, waste collection became a requirement of space suit design. The Apollo modules had enough volume for the crewmen to move around, so they were able to remove their suits in flight and wear more comfortable clothing. Undergarments similar to diapers were used for waste collection.

The waste collection equipment on Skylab included a fecal/urine collector mounted on a wall perpendicular to the floor in the Waste Management Compartment (WMC). The collector was similar in appearance to an Earth toilet seat and used airflow to dispose of the waste. Collection bags were inserted into the collector before use, and used as contingency equipment when the collector failed. Some waste was dried and returned to Earth in the bags for analysis; the rest was disposed of through the Trash Airlock (TAL). The TAL provided a means for daily transfer of waste from the habitable, pressurized areas of the spacecraft to the unpressurized waste tank (Johnson, 1974). Some of the crewmen did not like the orientation of the wall collector because it forced them to face the floor during use. The lack of a privacy curtain or other device between the waste collection and grooming equipment, located on a nearby wall, was also criticized. Because crew activities were scheduled parsimoniously, occasions would arise when there was

simultaneous use of the two facilities. The close proximity of the two facilities made it unpleasant for both participants (Dalton, 1975). Skylab crews were also dissatisfied with the infrequent wiping of the waste collection unit, the odorous crevices in the urinal drawer, and the leakage of the urinal bags (Johnson, 1974).

3.2.3.1.2 SPACE SHUTTLE ACTIVITIES

The Space Shuttle provision for body waste collection is an integrated, multifunction Waste Collection System (WCS) similar in appearance to an Earth toilet, as illustrated in Figure 8. Major components of the WCS are:

- (1) commode
- (2) compactor
- (3) urinal
- (4) fan separators
- (5) odor/bacterial filter
- (6) vacuum vent
- (7) auxiliary wet trash storage
- (8) controls.

The functions of the WCS include:

- (1) feces collection, storage, and dehydration
- (2) urine treatment and transportation
- (3) waste water treatment
- (4) waste systems interface (Lew, 1984b).

On Space Shuttle flights, WCS cleaning is scheduled as a daily in-flight activity. Biocidal cleanser, disposable gloves, general purpose

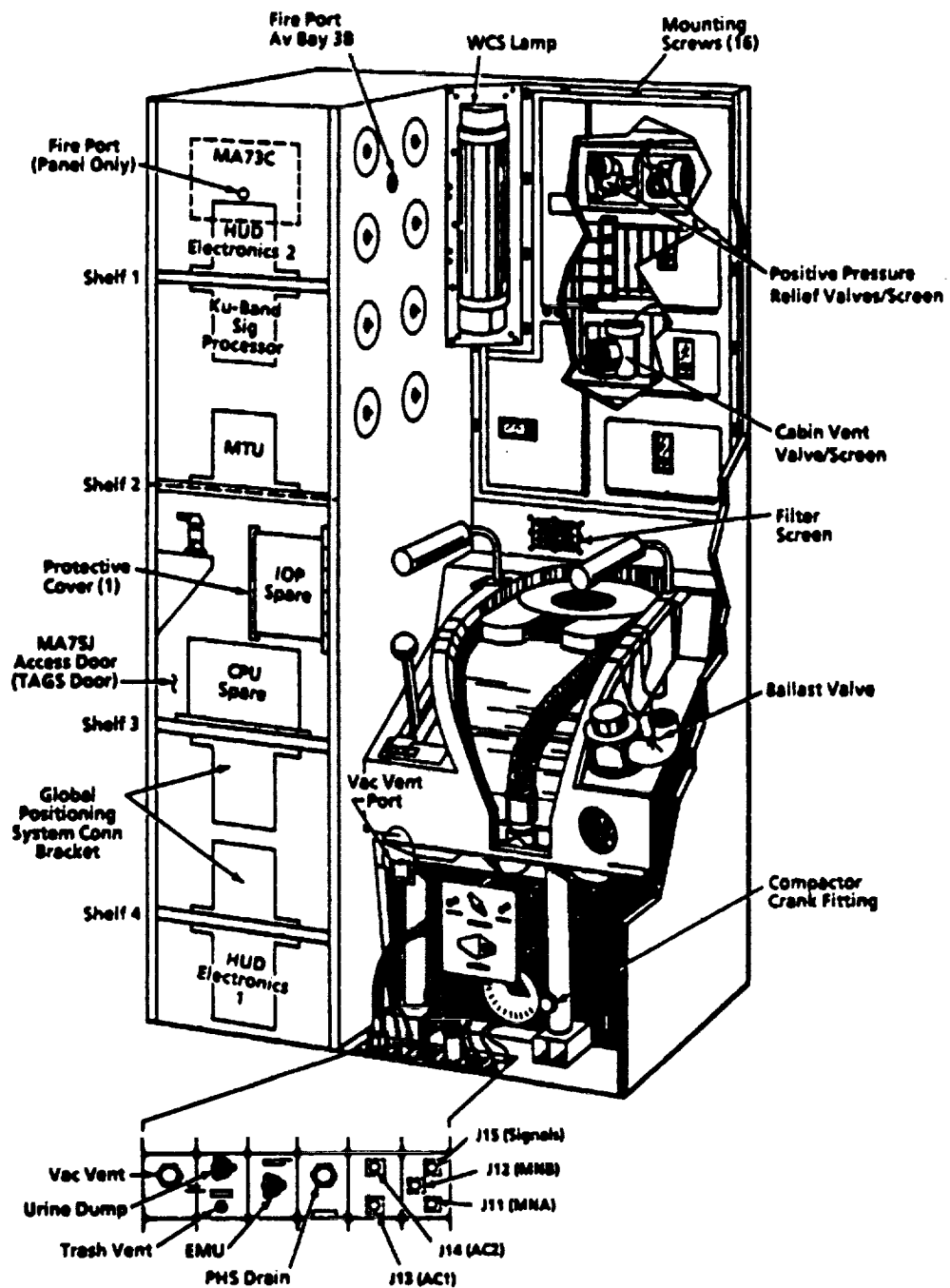


Figure 8. Waste Collection System

wipes, small wet wipes, and a water hose are provided for cleaning the unit (Lew, 1984b). The seat on the WCS is cleaned with wet wipes after each use, but the inner surfaces are wiped only when necessary. The odor/bacteria filter is replaced as needed.

Some Space Shuttle crewmembers have found the WCS unit to be inadequate. Crewmembers since STS-9 complained that dirty, brown dust floated out of the commode on the last few days of the mission, and that the airflow did not entrap the last pieces of fecal material (Myers, 1983d). JSC IFM (In-Flight Maintenance) engineers have found this brown material adhering to WCS walls and to the overhead panel (MO10W) during turnaround periods at KSC (J. Johnson, 1988). These problems led to infrequent use of the unit for fecal collection on several missions. In fact one crewmember stated that the system was better than Apollo, but a step backwards from Skylab. The problem was traced to the slinger unit on the commode. The slinger unit is a rotating cylinder with a series of tines that shred the feces and accelerate the wastes to the commode inner wall where it adheres in a thin layer around the periphery. On at least one flight, the slinger failed, and a prybar from the IFM Tool Kit was used to chip fecal material from inside the commode (J. Johnson, 1988). The slinger has since been removed and replaced with a fecal compactor.

Several changes have been made to the WCS unit based upon crew comments:

1. The seatbelt has been replaced with thigh bars to provide better stabilization.
2. Personal funnel attachments are provided for personal sanitary reasons, and allowing separate male/female capabilities.
3. Airflow in the urine hose was increased from 8 to 10 CFM to entrap liquid waste.
4. Airflow in the WCS was increased from 3 pounds per day to 6 pounds per day to

alleviate commode tank odor.

5. Hose connector to fan separators A or B is movable to facilitate fan duty cycles.

6. The fecal compactor replaced the slinger unit, thereby requiring less inflight maintenance and fewer operating failures.

7. A "dirty towel can" (Fig. 9), called the "coffee can" because of its resemblance to the same, and a second wet trash storage/vent were added to aid in disposal of used washcloths and wipes, as well as provide additional ventilation.

8. A feces/emesis switch was removed from the commode, and the personal hygiene station (handwasher) was removed due to continuous operating failures.

9. A lever/switch was installed that allowed for selectivity in use of Fan Separator 1 and Fan Separator 2.

One problem still to be resolved is waste management on the Extended Duration Orbiter (EDO) missions of 16-30 days. The fecal compactor tank does not have the capacity for flights exceeding 15 days. A redesign of the commode unit and a more efficient storage and disposal system is needed.

3.2.2.1.3 SPACE STATION FREEDOM CONSIDERATIONS

The collection system planned for Space Station Freedom must correct the mechanical problems experienced on Space Shuttle missions. Therefore, the WCS unit would require a modification or redesign to insure sufficient airflow. The RFP for Space Station Freedom identified a unit sized to anthropometric specifications in a commode compartment large enough to permit donning, doffing, and temporary stowage of clothing (NASA, 1984c). Cleaning requirements for the new unit will depend on design specifications presently under investigation, but the following characteristics should be considered:



Figure 9. Dirty Towel Can Waste Disposal in WCS

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

1. The unit should eliminate microbial and chemical activity of the waste.

2. Waste treatment should commence immediately after collection.

3. Waste products should be isolated from intravehicular and extravehicular environments.

4. Waste products should be contained completely by the WCS so that surface cleaning is minimized.

5. Cleaning the unit should require minimal or no crew involvement.

6. The unit, nevertheless, should be designed for on-orbit maintenance.

3.2.3.2 SHOWERS

Showers provide whole body washing capability under the control of accurate and automatic water temperature regulation.

3.2.3.2.1 HISTORICAL BACKGROUND

Because Mercury missions were one day or less in duration, the crewman flew without body cleaning provisions. With the longer Gemini and Apollo missions, wet wipes and towels were added to facilitate partial body cleaning. A water dispenser, used primarily for food rehydration, was available for wetting washcloths to clean faces and hands. During Apollo, the vastly enlarged habitat permitted removal of the spacesuit for whole body "sponge bathing" (Johnson, 1974).

Skylab was the first spacecraft to provide a shower for whole body washing. The shower was a circular unit approximately 30 inches in diameter equipped with a water hose and a privacy curtain. Excessive cleanup time, however, contributed to the infrequent use of the shower. The shower was collapsible, and all surfaces had to be vacuumed to remove water droplets before it could be stowed. Since the vacuum cleaner lacked sufficient suction, the

entire process was slow and tedious (Johnson, 1974). Several crewmembers stated that they did not get too dirty or too sweaty in flight because a relatively clean, low-humidity atmosphere was maintained. Crewmembers found that a sponge bath after exercise or at night was sufficient (Johnson, 1975).

3.2.3.2.2 SPACE SHUTTLE ACTIVITIES

The short duration of Space Shuttle missions and the lack of room onboard contributed to the design decision that a shower would not be provided. Crewmembers are provided individual personal hygiene kits for daily use. The kits include soap, toothbrush, toothpaste, shaving cream, razors, lotion, and antiseptic lotion (NASA, 1983a). Crewmembers take sponge baths as needed, such as after exercising, and towels and washcloths are allotted to each crewmember according to the flight duration. These supplies are adequate for whole body washing as long as small amounts of soap and water are used.

3.2.3.2.3 SPACE STATION FREEDOM CONSIDERATIONS

Personal cleanliness on Space Station Freedom will center around whole body showers provided in each of the habitable modules. Crewmembers will be allowed to shower every three days, a number restricted by water processing equipment and tank size. Each shower unit will contain hot, cold, and mixed water controls and permit hair and scalp washing. The design of the unit will accommodate the use of traditional bath soaps and shampoos. A temperature-controlled, private dressing area will be adjacent to the unit, and waste water will be transferred to a disposal tank or recycling facility (NASA, 1983b).

Research on Earth showed that removing soap residue from shower surfaces immediately after use reduced the growth of mildew and bacteria (Libien, 1976). Lowbury (1975) also found that wiping down shower walls with absorbent material after each use

reduced the growth of bacteria. This type of preventative maintenance is ultimately more efficient than cleaning on an "as needed" basis because soap residue is more difficult and time-consuming to remove after hardening. Daily cleaning with a low-sudsing detergent and weekly cleaning with a biocidal agent, therefore, may be sufficient for most showers. Daily disinfecting procedures may be necessary only in special situations, such as after bathing infected wounds and major skin irritations.

Minimal cleanup time should be a major consideration in the design of the new shower unit. In addition, it should be designed so that it can be repaired mechanically and/or electrically, as necessary, to prevent its becoming inoperative. The design should include the removal of waste water and soap residue, as well as eliminate cracks and crevices to reduce leakage and bacterial growth. The use of abrasive substances for cleaning should be avoided because they might scratch the surfaces of the unit and create grooves for dirt and bacteria to lodge. The cleansing agent chosen for shower cleaning must be judged safe for use in the Space Station environment, and be compatible with onboard water reclamation and waste disposal systems.

3.2.3.3 HAND/FACE WASHERS

Hand and face washers provide water and cleansing agents for hand and face cleaning under the control of accurate and automatic regulation of water temperature. These units should be capable of directing water flow to face or hands without leakage into the cabin atmosphere, and contain integral "clean-up, soak-up" capabilities, to remove excess water not used for washing.

3.2.3.3.1 HISTORICAL BACKGROUND

The first handwasher, used on Skylab, was a recessed metallic box mounted on a wall in the WMC. The equipment consisted of a water hose, handrail, squeezer bag, and soap holders (Johnson, 1975). The handwashing proce-

dures were similar to the Earth procedure performed at a wash basin with the exception of removing excess water from the washcloth. The hand-operated squeezer provides that function. When the washcloth was inserted into the squeezer area and latched shut, the entrained water was forced out of the washcloth by piston action and directed into a replaceable squeezer bag.

The major complaint about the handwasher was the inability of the crew to work directly with the water flow without splashing it all over the WMC. Water squirted past the squeezer seals on many occasions. Crewmen suggested that a transparent enclosure over the unit would prevent water spills. Such an enclosure would have allowed for spraying water on small items such as razors. Other comments indicated a need for a larger squeezer to accommodate towels, and a smoother surface to eliminate bacterial growth in the crevices (Johnson, 1975).

Cleansing the outer surfaces and crevices of the handwasher with biocide wipes was scheduled after each use, but the crew found this task to be too time consuming. Wiping off the handwasher took at least 10 minutes even if there was a small amount of water on the surfaces. Consequently, many crewmembers chose to use the drinking water hose for handwashing because it required less time. This example alone illustrates the importance of considering cleaning requirements in the design of new equipment for Space Station Freedom. If crews cannot easily maintain the equipment, they will avoid using it.

3.2.3.3.2 SPACE SHUTTLE ACTIVITIES

The handwasher, or Personal Hygiene Station (PHS), on the Space Shuttle was an enclosure consisting of a sphere 12-inches in diameter, two front sleeves for crewmember access, a water nozzle at the top, and a drain at the bottom. Water temperature was controlled from cold to hot by means of a mixing valve, and water flow was controlled by ac-

tivating a lever protruding through the left sleeve (NASA, 1983a). Since the unit was attached to the side of an optional unit (the galley), it was not included on every mission.

For non-galley flights, a hygiene water valve, attached to an eight-foot, 1/4" diameter hose, called the PHS hose (Fig. 10), was provided for handwashing (Lew, 1983) as an integral part of the Operational Water Dispenser Assembly (OWDA). When either the PHS or the OWDA was used, the fluid waste was discharged into the WCS.

The Personal Hygiene Station on the Space Shuttle was no more satisfactory than its Skylab counterpart. Crewmembers complained that water collected at the bottom of the unit, requiring at least 10 minutes to remove. Mechanical and plumbing problems were also prevalent (conversation with L. W. Lew, NASA JSC Training Division, 1984). The PHS was scrapped fairly early in the Shuttle program, and the PHS hose and water valve were used on every flight thereafter for wash-water needs. On flights where the galley was flown, the PHS hose was connected by a quick-disconnect to an auxiliary port on the aft portion of the OWDA. The hose and valve assembly were stored in the In-Flight Maintenance Contingency Hose and Cable Assembly.

Several anomalies occurred in the operation of the galley during Shuttle missions. On occasion, the galley water would not flow, due to electrical problems; on another, the rehydration station on the galley failed to operate due to a clogged needle. The first problem was solved on orbit when the crew kicked the galley whenever it failed; it seemed to temporarily "fix" the problem. The clogged needle problem was solved by using a piece of safety wire from the IFM tool kit and clearing the clog in the rehydration needle. Subsequently, a spare PHS water valve, rehydration needles, and water hoses were carried in the IFM kit, as well as a free fluid disposal nozzle, which could be used to clear bubbles

of free water from the cabin by connecting the nozzle and hose assembly to the Contingency Cross-Tie Waste Quick Disconnect on the WCS wall, and dumping them overboard.

3.2.3.3.3 SPACE STATION FREEDOM CONSIDERATIONS

The hand/face washing units proposed for Space Station Freedom will be the first units of their kind to facilitate washing. An enclosed basin and a directable water supply have been discussed. In the design, non-essential cracks and crevices should be avoided, and seals should be secure to prevent growth of bacteria and the leakage of water. Requirements for cleaning units should be similar to those stated earlier for the shower, and take into account the unsuccessful efforts already experienced on Skylab and Space Shuttle flights. Because frequent cleaning would be required of any device that uses soap and water, the following specifications for cleansing agents should be considered.

1. Cleansing agents should allow for maintenance of a normal balance of microbial flora.

2. Cleansing agents should not produce deposits of film on the body or on the hand/face washing equipment.

3. Cleansing agents should be non-toxic, non-flammable, and non-explosive in all their states.

An alternative to the handwashing unit in some areas might be a waterless procedure. Several paste products readily available have received favorable reports. Two such products, PLY (manufactured by the Milburn Company) and PAX LIGHT DUTY (manufactured by Packwood Manufacturing Company) were evaluated aboard submarines by the United States Navy. Both of these products cleaned effectively and caused no skin irritations, chapping, offensive odors, or healing delays (Gillen, 1956). PLY received higher ratings than PAX LIGHT DUTY because it was

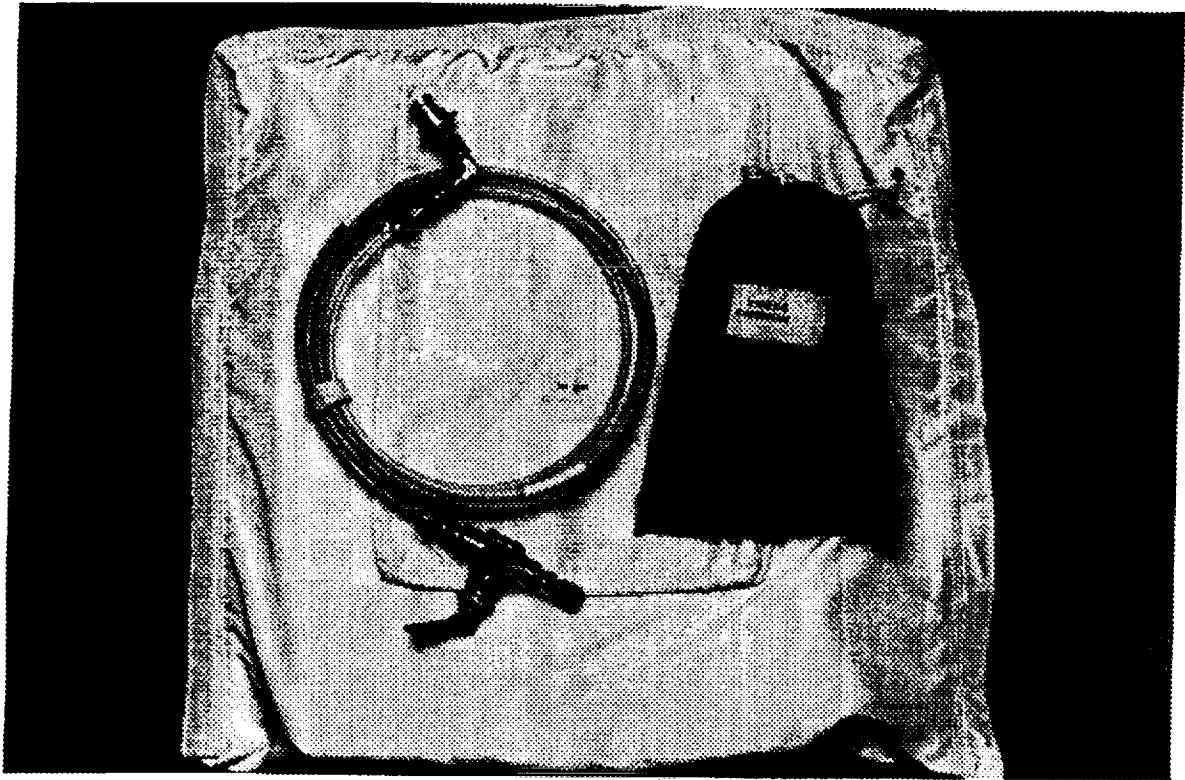


Figure 10. Water Nozzle and PHS Hoses

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

better at eliminating heavy carbon deposits, a requirement that might be important in certain work areas on Space Station Freedom. The use of a moisturizing, waterless hand cleaner may be helpful for dry skin, especially in a low-humidity environment.

On Space Station Freedom, a waterless system would provide backup for other personal hygiene systems as well as eliminate the need for a complex water system throughout the entire station. Water could then be restricted to essential areas, such as galley, wardroom, waste collection, and grooming facilities. Reducing the number of hand/face washing units could offer the following advantages:

- (1) minimize water leakage and spillage
- (2) reduce cleaning tasks
- (3) decrease water consumption
- (4) conserve power associated with water treatment, disposal, and transfer.

3.2.3.4 GROOMING COMPARTMENTS

Grooming compartments provide capability for oral hygiene, shaving, hair removal, nail clipping, and other personal cleanliness activities.

3.2.3.4.1 HISTORICAL BACKGROUND

On Skylab, personal grooming activities were performed in the waste management compartment (WMC). This was the first in-flight facility of its kind. Surface cleaning tasks in this area focused primarily on the walls, floors, filters, and mirrors. Adjacent to the WMC was a drying station for washcloths and towels. Cleaning this area with biocide wipes was scheduled weekly; however crewmen were encouraged to practice continuous maintenance of all surfaces by immediately wiping up spills (Brown, 1976). The low humidity in the cabin atmosphere also helped to keep

these surfaces dry.

3.2.3.4.2 SPACE SHUTTLE ACTIVITIES

On the Space Shuttle, the grooming compartment (personal hygiene area) is located on the port side of the middeck forward of the WCS compartment. Because Shuttle missions are of short duration, cleaning the personal hygiene area with biocidal wipes is not scheduled. Between missions, surface cleaning is performed during Shuttle turnaround at KSC by maintenance crews.

3.2.3.4.3 SPACE STATION FREEDOM CONSIDERATIONS

Two grooming compartments equipped with appropriate stowage, restraints, mirrors, and water receptacles are planned for Space Station Freedom. These compartments will be designed to accommodate the performance of all grooming activities using commercial preparations and equipment in a manner similar to those on Earth. They will contain hand/face washing units with enclosed basins and will accommodate hair removal (NASA, 1983b).

Mold and mildew flourish on surfaces which are damp, poorly ventilated, and poorly lit (Libien, 1976). Therefore, grooming compartments in particular should be dried, aired, and illuminated regularly. Cleaning would be facilitated by smooth surfaces on walls, floors, and counters and an effective air revitalization system. Cracks and crevices should be avoided in the design of equipment housed in these compartments so a thorough cleaning job can be performed. Weekly cleaning with a biocidal detergent is recommended to remove dust and dirt from all surfaces in the grooming compartments since research has shown that the exclusive use of soap with no biocidal agent results in a high likelihood of bacterial growth (Werner, 1975). Air filters in the grooming compartments should be changed or vacuumed frequently to remove hair, nail clippings, and other particles. Finally, the grooming compartment should be illuminated

sufficiently to detect dirt and bacteria growth and aid the crewmember in viewing areas to be cleaned. Air ducts, hoses, and other passageways that conduct cabin or avionics air should be designed so that they foster the least amount of bacterial/microbial growth within their confines, and inspection and cleaning routines perfected to prevent growth throughout the cabin atmosphere.

3.2.4 FOOD PREPARATION AND CONSUMPTION

The food preparation and consumption equipment provides food rehydration, heating, and stowage capability, as well as simultaneous dining facilities for the entire crew.

3.2.4.1 HISTORICAL BACKGROUND

During early space flights, meals were restricted to items that could be pureed and placed in metal squeeze tubes or compressed into bite-sized pieces. Freeze-dried foods were introduced in the Gemini program and spoon-bowl packaging was added during Apollo (Larkin, 1982). Inflight food preparation included the rehydration of food via water valves. Cleanup was accomplished during these missions by disposing of the food containers immediately after meals. The success of this approach to housekeeping varied with the mission and the crewmen involved.

On Skylab flights, food preparation and cleanup was facilitated by a food table, freezer, chiller, and heater. The food table allowed three crewmen to prepare and consume food simultaneously (Johnson, 1976). Cleaning the area and equipment was scheduled immediately after meals. Since the location of the trash bags was not considered in the interior design, crewmen hung trash bags on snaps in the galley area to facilitate cleanup after meals. In zero-gravity, these bags stuck out from their locations at 45-degree angles and, consequently, obstructed pathways (Johnson, 1976).

Even though surface tension generally

holds food together in zero-gravity, liquid spills were common on Skylab after shaking a drink container or cutting a membrane off a heated meat dish. Spills frequently adhered to wall surfaces and occasionally went through the triangle-grid floor. The latter spills were sometimes difficult or impossible to reach. In general, surface cleaning was complicated by the interior design. There were too many nooks and crannies where food spills could lodge. Eventually, these spills became a source of odor (Johnson, 1976).

Cold storage areas also required frequent cleaning and monitoring (Johnson, 1976). Defrosting the freezer proved to be a chore because the appropriate tools were not aboard. A regular ice scraper or putty knife would have been useful for the removal of ice. The ice build-up in the freezer, in fact, resulted in a sealing problem between two units. Ice would form between the freezer and the chiller, setting up an airflow path that would actually speed up the formation of more ice. The small inner doors of the freezer also made cleaning more difficult because they did not allow access to some of the corners and inner surfaces. In addition, moisture build-up in the chiller required frequent wiping to prevent the formation of rust on the food cans. Since both food and research supplies were stored in the chiller, contamination was also a potential danger.

3.2.4.2 SPACE SHUTTLE ACTIVITIES

The food preparation system on the Space Shuttle consists of the following major components: (1) food, (2) water dispenser (Fig. 11), (3) trays, (4) warmer, (5) stowage, and (6) galley. The galley is a multi-purpose unit which provides a centralized location for one crewmember to handle all food preparation activities for a meal. The galley contains an oven, a rehydration unit, condiments and wipe dispensers, and accessories (Lew, 1983). Food is rehydrated via a water dispenser which is located in the middeck forward area. When the galley is not included on a mission,

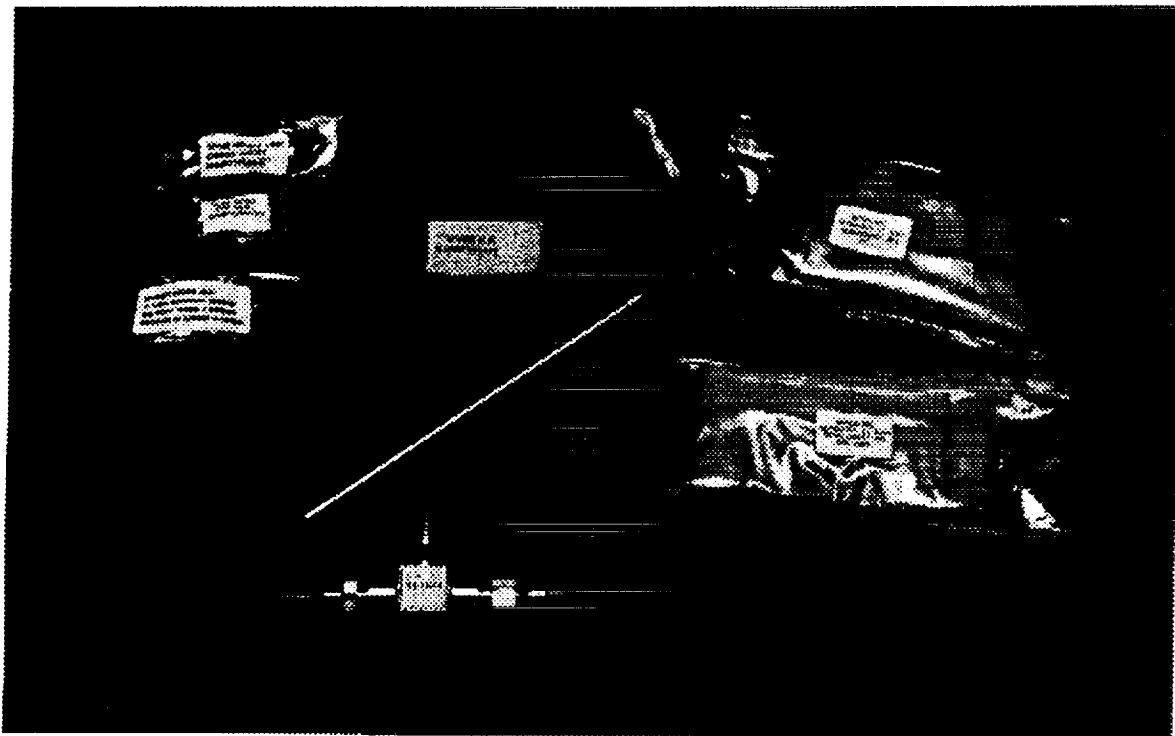


Figure 11. Water Equipment

[Counter-clockwise from upper left: spare needle assembly for orbiter/galley, spare needle assembly for OWDA, wrench needle assembly, vacuum probe attachment, contingency water dispenser, water/gas separator assembly (2).]

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

food is heated by conduction in a food warmer, which resembles an aluminum suitcase. The warmer is attached by velcro to a stowage locker in the middeck of the vehicle (Gillan, 1984).

On both Skylab and Space Shuttle, cleaning the galley was augmented by two cleaning systems: the vacuum cleaner and the wipes (Brown, 1976). The vacuum cleaner system, discussed in Section 3.1, consists of a suction unit, attachments, and bags which allow for the collection and retention of both wet and dry food matter, via a gravity substitution airflow. The wipes system consists of four basic types of wipes: (1) dry wipes which measure 5 x 17 inches, (2) tissues which measure 5 x 8 inches, (3) wet wipes which measure 5 x 7 inches, and (4) biocide wipes which measure 6.5 x 7.5 inches. Dry wipes and tissues are essentially the same items except for size, and are fabricated from Kimberly Clark Company 3472 Kaydry material. Wet wipes are manufactured of flexible crepe paper and saturated with Zepherin, a benzalkonium chloride disinfectant solution. Biocide wipes are made of non-woven cotton fiber and contain Betadine, an iodine solution (Johnson, 1974).

Meals typically are consumed in the mid-deck on Space Shuttle missions. Food spills are common occurrences, but crews are comfortable with clean-up procedures. The use of cloth material, rather than wipes, is preferred. In fact, dirty undershirts are presently being saved on Space Shuttle missions for cleanup operations (Myers, 1983d). The increased size and absorbency of the undershirts make them more desirable for big cleaning tasks. Space Shuttle crews also suggest that a can of biocide spray be provided, in addition to the biocide wipes, for use with the cloth material.

3.2.4.3 SPACE STATION FREEDOM CONSIDERATIONS

Food preparation and consumption will take place in the galley/wardroom facility. This facility will be one major habitation area

in Space Station, consisting of two adjacent substations, the galley and the wardroom. The galley will provide equipment and supplies necessary for food stowage, food preparation, and cleanup. Food and drink stowage will be accomplished in a refrigerator, a freezer, and ambient lockers. Food preparation will be accommodated by convection and/or microwave ovens. The wardroom will accommodate the entire crew simultaneously for dining or meeting. It will contain magnetized tables, entertainment resources, and communication equipment (NASA, 1984b).

General cleaning of the galley/wardroom facility will be accommodated by at least five different subsystems: (1) a trash stowage unit, (2) a trash compactor, (3) a zero-gravity dishwasher, (4) a vacuum cleaner and attachments, and (5) housekeeping supplies. Even though the design of the area will dictate its cleaning requirements, the existing vacuuming subsystem will require modifications and the wiping subsystem must provide larger, more absorbent wipes.

Surface cleaning in the galley/wardroom should be similar to procedures established for the grooming compartments. A fresh, dry, well-lit environment must be maintained. Because food is a common source of odor and bacterial growth, a biocidal cleansing agent is recommended for cleaning all surfaces. Areas containing velcro should also be given special consideration since food will rapidly adhere to its surface. Replacement of the velcro after several washings is recommended, and care must also be taken to avoid breaking the fiber hooks.

3.2.5 SLEEP AND RELAXATION

Sleep and relaxation equipment provide crew accommodations for resting, lounging, dressing, and personal stowage.

3.2.5.1 HISTORICAL BACKGROUND

Sleeping accommodations prior to Skylab were rudimentary. In the Mercury and Gemini

modules, the crew slept in pressurized spacesuits, strapped in their seats or couches (Dalton, 1974b). The Apollo Command Module, however, had sleep restraints resembling zip-up hammocks or sleeping bags. On Skylab, three individual sleep compartments were provided. Curtains, partitions, and stowage lockers separated the areas; a grid floor contained a diffuser for varying the airflow; and a grid ceiling provided ventilation. Stowage lockers which housed trash, clothing, and other personal items provided a noise and visual barrier (Dalton, 1974c). Each crewman was responsible for keeping his own compartment clean.

3.2.5.2 SPACE SHUTTLE ACTIVITIES

Flight activity requirements make private crew quarters on some Space Shuttle missions necessary equipment. On missions which require dual sleep shifts, the sleeping provisions consist of three rigid, rectangular-prism shaped units with bag inserts, eye covers, and ear plugs. These units are equipped with a fluorescent light, ventilation ducts, and personal stowage pockets (Lew, 1984a). When dual sleep shifts are not scheduled, these units are removed and standard sleeping accommodations then consist of sleeping bags. Crewmembers sleep restrained in seats or sleeping bags, or they float freely within the vehicle.

3.2.5.3 SPACE STATION FREEDOM CONSIDERATIONS

Because of the long duration of Space Station Freedom missions, crewmembers will be provided with private crew quarters which will contain a sleep restraint, a portable work area, personal stowage, a communication unit, and entertainment equipment (NASA, 1984b). Cleaning the crew quarters will require housekeeping procedures similar to bedrooms on Earth. Airing out the compartments, wiping off surfaces, changing the sleep surfaces, and putting away clothing and other personal items are a few of the tasks that must be performed. These tasks, which must be

scheduled, will involve both daily and weekly responsibilities.

Generally, a daily straightening routine prevents sleeping quarters from requiring an inordinate amount of weekly cleaning time. The following tasks are suggested: (1) freshening the air supply by opening a door or turning on a vent, (2) organizing the environment by restowing clothing, books, etc., and (3) smoothing out the sleeping units. Dusting and disinfecting surfaces should probably be a weekly task. Removing dust and foreign matter from the atmosphere by means of automatic filtration should be a continuous process.

A laundry facility for bedding, towels, and clothing has been proposed for Space Station Freedom. The reference configuration provides for both a washer and a dryer (NASA, 1984b). Their presence onboard would reduce the amount of washables necessary for a 90-day mission. The benefits of having a washer and dryer onboard, however, should be weighed against the costs of increased power and water utilization. Therefore, this facility may not be a part of the Space Station Freedom system. When a decision is made, the impact of a laundry facility on housekeeping operations should be assessed.

3.2.6 SUPPORT OPERATIONS

Support operations include a variety of activities, such as maneuvering the vehicle, conducting laboratory experiments, repairing equipment, and administering medical care. Cleaning procedures for operations equipment, therefore, are dictated to a large extent by the function and design. Hence, this section addresses general issues that would be relevant to all operation equipment.

3.2.6.1 HISTORICAL BACKGROUND

Prior to Skylab, surface cleaning tasks were outlined to support specific spacecraft operations. Chores were planned to accommodate mission requirements and modified

when necessary. For example, windows, camera lenses, and filters were cleaned only when necessary. Very little attention was given to housekeeping issues, consequently, the spacecraft became quite dirty.

On Skylab, surface cleaning tasks were defined prior to the missions and scheduled for each crewmember on a checklist of the flight data file (Brown, 1976). The checklist included the task number, crewmember name, required equipment (including its location), and detailed crew procedures. Servicing equipment, resupplying stowage, handling waste, and disinfecting surfaces were the types of jobs assigned. However, many of the assigned housekeeping tasks were not performed until the end of the mission, and some were not performed at all; therefore, habitability declined with each Skylab mission, and the crew of the fourth Skylab mission reported a dirty, smelly spacecraft (Dalton, 1975).

3.2.6.2 SPACE SHUTTLE ACTIVITIES

A lens cleaning kit containing dry tissues and lens cleaning fluid are carried on all orbiter flights. This kit has been used to clean the covers of experiments as well as the windows of the orbiter prior to taking photographs.

3.2.6.3 SPACE STATION FREEDOM CONSIDERATIONS

Regular cleaning of the operation equipment on Space Station Freedom will require the integration of equipment and procedures. All equipment should be designed to minimize cleaning time. Inaccessible areas, which are a haven for loose or floating materials, should be designed with close-out devices or covers compatible with adjoining surfaces. Procedures for cleaning and maintaining these areas must be incorporated into appropriate daily, weekly and monthly crew activity schedules. For example, the medical care facility may require disinfecting more often than the flight deck and the research

laboratory may require closer monitoring of contaminants than the repair shop.

Until design specifications for the operation equipment are available, detailed cleaning requirements for Space Station Freedom can not be defined. However, exposed walls, panels, windows, and screens should be smooth to discourage the build-up of dirt. Also, grid-type coverings should not be used, filters should have easy access, and cracks and crevices should also complement an efficient ECLSS by providing easy access to filters and other areas needing regular maintenance.

3.2.7 SPACE STATION FREEDOM GUIDELINES

The following guidelines should provide direction for the design of a surface cleaning system for Space Station Freedom:

1. The mechanical problems associated with the WCS unit on the Space Shuttle must be corrected, and the commode compartment must be large enough to permit donning, doffing, and temporary stowage of clothing.
2. The airflow in the WCS should be sufficient to permit entrapment of solid and liquid waste.
3. The WCS air filtering system should be improved to prevent an excess of air-entrained debris from clogging screens designed for other purposes.
4. A whole body shower should be standard equipment. Minimum cleanup time should be a major design consideration for this unit.
5. The detergent used to clean surfaces should be compatible with onboard water reclamation systems.
6. Body and surface cleansing agents should be non-toxic, non-flammable, non-explosive, and low sudsing.

7. The applicability of waterless hand-cleaning procedures should be assessed with respect to cost, toxicity, and water availability. A moisturizing ingredient is suggested to minimize skin irritations in a low-humidity environment.

8. All personal hygiene equipment should be void of non-essential cracks and crevices so bacteria growth and odor is inhibited.

9. All surfaces should be regularly dried, aired, and illuminated to prevent mold and mildew growth.

10. Walls, panels, windows, camera lenses, and screens should have smooth surfaces to discourage the build-up of dirt and to facilitate the cleaning process.

11. Cleaning and/or replacing air filters should be scheduled regularly.

12. All galley/wardroom surfaces should be void of cracks and crevices where food and water spills can lodge.

13. Large, absorbent wet and dry wipes should be provided to facilitate major cleanup tasks.

14. A biocide spray dispenser should be provided in addition to the biocide wipes.

15. Time should be allotted for daily straightening and weekly dusting and disinfection of all surfaces in the crew quarters.

16. Surfaces which cannot be easily cleaned should be fitted with close-out devices.

4. LOGISTICS

4.1 INTRODUCTION

Logistics encompasses four main areas relating to materials and personnel: (1) procurement; (2) distribution, such as placement and classification; (3) maintenance,

such as inventory control; and (4) replacement or restowage (The American Heritage Dictionary, 1982). Logistics within a spacecraft usually emphasized the distribution, maintenance, and replacement of materials. A well-developed logistics system can be an important factor in developing and maintaining a spacecraft environment that promotes crew efficiency and productivity because the system: (1) provides a systematic and orderly method of stowing materials; (2) provides a method of inventory control that accounts for the quantity of materials on hand; and (3) reduces the time needed to locate, remove, or replace an article.

4.2 PROBLEM STATEMENT

A logistics system should provide an efficient method of stowing and accounting for materials. Crewmembers have criticized the location coding system, the identification system, and the inventory system of past and present spacecraft. An improved logistics system should be developed to improve the efficiency and productivity of the Space Station crew.

4.3 SKYLAB EXPERIENCES

Skylab was the first program to emphasize the need for a spacecraft design that would increase crew efficiency and productivity. Therefore, the historical review of logistics in a spacecraft will begin with the Skylab experiences.

Logistics was important for the efficiency and productivity of Skylab crewmembers. Most of the required materials, such as equipment, personal hygiene articles, and consumables, were procured and distributed within the spacecraft prior to launch. Materials were stowed in lockers throughout the vehicle. A combination of numbers and letters were used to identify stowage locations and control/display panels. This system, however, was inefficient in identifying the locker contents. The crewmembers emphasized the need to establish a better distribution system that could: (1) adequately handle the mag-

nitude of items required to be located, (2) efficiently identify the contents of the lockers, and (3) easily be learned (NASA, 1982).

Logistics maintenance was accomplished by a periodic inventory check. Materials were hand-counted and tabulated, and new supplies were delivered with the next crew. This method of inventory control was inefficient.

Replacement of equipment in its original stowage location was seldom accomplished, causing the following problems: (1) little or no accountability of equipment location, especially after crew changes; (2) irrelevant classification and location system; and (3) loss of valuable crew time searching for misplaced articles (Dalton, 1975).

4.4 SPACE SHUTTLE ACTIVITIES

Overall, the logistics system on the Space Shuttle is less complicated than on Skylab, due to the shorter mission duration and smaller area for stowage. The materials required for in-cabin experiments and crew habitability are stowed in the middeck lockers. The crewmembers on STS-5 expressed their concern about the logistics system on-board (Myers, 1982b). Some of the problems the crewmembers encountered were: (1) similar articles, such as camera parts, were not stowed in the same general area causing crew confusion; (2) contents of the locker trays were not identified on the locker door, increasing crew time to locate an article; and (3) equipment was difficult to replace, increasing crew time to restow the item (Myers, 1982b).

4.5 SPACE STATION FREEDOM CONSIDERATIONS

As stated by NASA, "The ability to use man in a highly productive way aboard the Space Station Freedom is a key main objective" (NASA, 1984c). This main objective can be accomplished by the development of a well-defined and usable logistics system. NASA requirements for the system include: (1) minimum time for preflight training of crewmembers; (2) minimal effort and time for

maintenance, repair, and replacement of equipment; (3) maximum use of automation where appropriate; (4) limited resources available, such as power, water, and stowage volume; and (5) nominal 90-day resupply cycle (NASA, 1984c). NASA also states that a logistics system should: (1) be simple, easy to use, and involve minimal crew time; (2) locate stowed equipment and consumables; (3) remove and/or restock specific items without disturbing adjacent locations; and (4) have an easy identification system for all stowed equipment (NASA, 1983b).

Further research will be necessary to develop and evaluate alternative methods for the development of a Space Station Freedom logistics system. A few possible alternatives that should be evaluated are:

1. The applicability of a data base management system. This type of system could integrate the logistics operations with a central computer system, providing accurate and timely information to crewmembers, such as equipment locations and material quantity levels.

2. The applicability of a computerized inventory system. For example, bar codes might be attached to consumables and reusable equipment. If an item were moved from module to module, a computer might read the bar code information on the item via a laser scanner. The computer could identify the item and account for the item's location at any time. A similar system is used currently at grocery store check-out counters.

3. The feasibility of a miniature passive electronic tagging system for inventory monitoring is currently under investigation by Lockheed Air Terminal. Tags are embedded in the packages in a similar manner to bar code strips and an interrogator electronically polls the packages to determine whether each tag is present or not. This system is more reliable and more flexible than the bar code system. It also is less task demanding and requires less time.

4.6 SPACE STATION FREEDOM GUIDELINES

Based on the Skylab and Space Shuttle experiences, as well as the Space Station Freedom requirements, several guidelines for the development of a logistics system can be identified:

1. The system should be able to manage the materials onboard and have an orderly method of stowing the materials.

2. Materials should be stowed in a location near the area of use and similar items within that area should be located near each other.

3. The method of stowing and restraining materials should permit easy stowage, removal, and replacement of the articles; should consume a minimal amount of crew time; and should not disturb adjacent locations.

4. The system should be capable of accounting for and locating all materials, whether in use or in stowage.

5. The system should provide quantity level and resupply interval information.

6. An identification and classification system should be developed. This system should identify all materials, be useful, be easy to learn, and be displayed on the exterior and interior of stowage receptacles.

7. The system should require a minimal amount of crew training, be easy to use, and involve minimal crew time.

8. The equipment used should be easy to maintain, repair, and replace.

9. The system should be flexible and expandable to adapt to the needs of Space Station Freedom systems.

10. Automation should be considered where applicable.

5. CONCLUDING REMARKS

The review of the housekeeping practices and problems during previous space missions indicates that housekeeping is crucial for habitability in space and that housekeeping procedures can have profound implications for productivity. The Skylab experiences demonstrate the importance of housekeeping on a manned spacecraft with missions of long duration. For example, problems in containing the growth of microorganisms on Skylab may have played a role in respiratory infections on Skylab 4 which resulted in lost productivity. Experiences on the Space Shuttle also illustrate the effect of housekeeping on habitability and productivity. For example, the design of the trash management system on the Space Shuttle requires crewmembers to handle trash extensively, which is an aversive and time consuming task.

In addition to identifying problems in housekeeping, the review of housekeeping in spacecraft has also yielded a variety of general systems as well as other systems on which housekeeping procedures must be performed. However, determining further and more detailed guidelines for the design will require additional research. This research should include: (1) housekeeping requirements for new equipment for the food system; (2) methods for housekeeping functions with minimal crew involvement through automation; (3) inventory control and logistics requirements; and (4) optional scheduling of housekeeping procedures. The research will produce a set of detailed guidelines. The final task in the design of the Space Station Freedom housekeeping system will be to monitor the implementation of housekeeping guidelines during Phase C and D of Space Station Freedom development.

BIBLIOGRAPHY

American Heritage Dictionary, American Heritage Publishing Co., copyright 1982.

Best, H. R.; and Clayton, A. J.: Controlling the Exotic Diseases: 2. Nursing Management. CMA Journal, vol. 123, 1980, pp. 867-871.

Brown, J.: Skylab Experience Bulletin Number 22, Evaluation of Requirements and Provisions for Housekeeping. NASA JSC Preliminary, unpublished, 1976.

Dalton, M.: Skylab Experience Bulletin Number 3, Architectural Evaluation for Sleeping Quarters. NASA JSC - 09537, 1974 (c).

Dalton, M.: Skylab Experience Bulletin Number 4, Design Characteristics of the Sleep Restraint. NASA JSC - 09538, 1974 (b).

Dalton, M.: Skylab Experience Bulletin Number 18, Evaluation of Skylab IVA Architecture. NASA JSC - 09552, 1975.

Gillan, D. J.: Approaches to the Design of the Food System for the Space Station. Lockheed - EMSCO - 20972, 1984.

Gillen, H. W.: Evaluation of Three Waterless Hand Cleaners. NASA AD663618, 1956.

Johnson, C. C.: Skylab Experiment M487: Habitability/Crew Quarters. NASA AAS74 - 133, 1974.

Johnson, M. L.: Orbiter Habitability Assessment of OFT Flights 1 Through 5. NASA JSC Preliminary, unpublished, 1983.

Johnson, M. L.: Skylab Experience Bulletin Number 8, Cleaning Provisions Within the Waste Management Compartment. NASA JSC - 09542, 1974.

Johnson, M. L.: Skylab Experience Bulletin Number 14, Personal Hygiene Equipment. NASA JSC - 09548, 1975.

Johnson, M. L. : Skylab Experience Bulletin Number 19, Food System. NASA JSC - 09553.

Kaplan, H. L. : Definition and Description of Contaminants in the Spacecraft Environment. The Physiological Bases for Spacecraft Environmental Limits, November 1979, pp. 17 - 56.

Larkin, D. : The Space Shuttle Operator's Manual. New York: Ballantine Books, 1982.

- Lew, L. W. : Food System and Dining Workbook, Food Sys 2102A. NASA JSC, February 1983.
- Lew, L. W. : Crew Systems Equipment Workbook, Crew Sys Eq 2102. NASA JSC, March 1984(a).
- Lew, L. W. : Waste Collection System Workbook, WCS 2102B. NASA JSC, March 1984(b).
- Libien, L.; and Strong, M. : Super-Economy Housecleaning. New York, Wm. Morrow and Co., Inc., 1976.
- Lockheed: Biotechnology. Lockheed-LMSC Advanced Systems Division, 1984.
- Lowbury, E. J. L.; Ayliffe G. A.; Geddes, A.M.; and Williams, J.D.: Control of Hospital Infection. London, Chapman and Hall Ltd., 1975.
- Moore, A. C.: How to Clean Everything. New York, Simon and Shuster, 1968.
- Myers, L. E.: Crew Debriefing Tapes STS-4. NASA JSC Building 45, Mailcode MD3, 1982(a).
- Myers, L. E.: Crew Debriefing Tapes STS-5. NASA JSC Building 45, Mailcode MD3, 1982(b).
- Myers, L. E.: Crew Debriefing Tapes STS-6. NASA JSC Building 45, Mailcode MD3, 1983(a).
- Myers, L. E.: Crew Debriefing Tapes STS-7. NASA JSC Building 45, Mailcode MD3, 1983(b).
- Myers, L. E.: Crew Debriefing Tapes STS-8. NASA JSC Building 45, Mailcode MD3, 1983(c).
- Myers, L. E.: Crew Debriefing Tapes STS-9. NASA JSC Building 45, Mailcode MD3, 1983(d).
- Myers, L. E.: Crew Debriefing Tapes STS-41C. NASA JSC Building 45, Mailcode MD3, 1984(a).
- Myers, L. E.: Crew Debriefing Tapes STS-41D. NASA JSC Building 45, Mailcode MD3, 1984(b).
- Myers, L. E.: Crew Debriefing Tapes STS-41G. NASA JSC Building 45, Mailcode MD3, 1984(c).

Myers, L. E.: Crew Debriefing Tapes STS-51A. NASA JSC Building 45, Mailcode MD3, 1984(d).

NASA: Operations Location Coding System for Crew Interfaces. NASA JSC-07387B, 1982.

NASA: Shuttle Flight Operations Manual. NASA JSC-12770, 1983(a).

NASA: Crew Interface Panel Space Station Habitability Requirements Document. NASA JSC-19517, December 1983(b).

NASA: Living Aboard the Space Shuttle. Space Education, vol. 1, 7, May 1984(a).

NASA: Space Station Configuration Description. NASA, August, 1984(b).

NASA: Space Station Definition and Preliminary Design Request for Proposal. NASA, September 1984(c).

Pierson, D.L.: DSO-0437: Microbiology Monitoring of Spacelab-3. NASA JSC-16725 Revision D, 1984.

Rappole, D.L.; Louvier, S.A.; and Sivaraman, G.K.: Food Service System for a Small Scale Space Station. Conrad Hilton College of Hotel and Restaurant Management, University of Houston, Houston, Texas, May 1983.

Tucker, G.; and Schneider, M.: The Professional Housekeeper. CBI Publishing Co., 2nd Edition, 1976, pp. 201-215.

Vitek: Automicrobic System Operators Manual. Vitek Systems, Inc., 1980.

Werner, H.P.: Investigations on the Efficacy of Surface Disinfection and Surface Cleaning Procedures. Index Medicus, August 1975, pp. 568-578.